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Future Aircraft Carrier Technology

Volume I: Overview

FUTURE AIRCRAFT CARRIER TECHNOLOGY

VOLUME I: OVERVIEW

Naval Studies Board
Commission on Physical Sciences,
Mathematics, and Applications
National Research Council

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PREFACE

In a letter to the Chairman of the National Academy of Sciences' Naval Studies Board, dated May 2, 1990, the Secretary of the Navy stated that the Conference Report on the Defense Authorization Act for Fiscal Year 1990 directed the Navy to commission an independent study of future aircraft carrier technologies. Stating further that the study should produce a "technology plan for the evolution of sea bases for the most efficient and economical accommodation of tactical air power in the first half of the twenty-first century," the Secretary requested the Board to conduct a study providing:

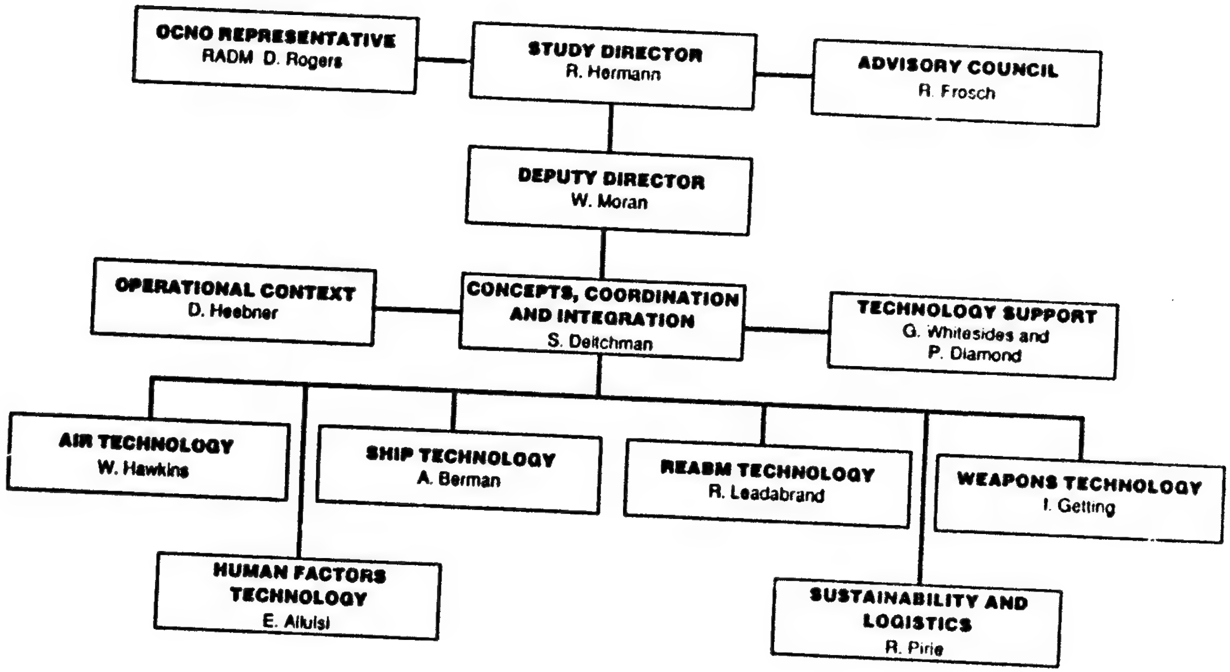
- a survey of applicable technologies,
- an assessment of risks associated with the development of these various technologies,
- estimated magnitude of the costs of developing these technologies for future aircraft carriers,
- the likely impact of technologies on aircraft carrier design.

The Secretary concluded by stating that he "envision[ed] that the result of this effort will be a menu of technology options that will affect future aircraft carrier designs," and that the final report of the requested study should be completed by June 30, 1991.

The Secretary's formal request for what became known as the Future Aircraft Carrier Technology Study actually began with preliminary discussions between the Board Chairman and Director and senior representatives of OP-05 and OP-08 on the evening of January 22, 1990. This meeting culminated in a verbal request for the Board to make preparations for undertaking the study contingent upon the Secretary's formal request. In response, the Board gained approval to undertake the study from the Commission on Physical Sciences, Mathematics, and Applications on January 26, and from the Governing Board of the National Academy of Sciences on February 6, 1990. The Board itself met on March 20, 1990, to approve the study plan drawn up over the intervening weeks.

The organizational structure of the study that emerged from the March 20 meeting is shown in the diagram on the following page. As is the Board's

FUTURE CARRIER TECHNOLOGY STUDY



practice with major studies, the Chairman became the Study Director, and all members were assigned key leadership or participatory positions. To serve the Board's usual oversight function, an Advisory Council composed of senior scientists, engineers, and operational experts was formed. During the course of the study the Advisory Council met twice to critique the study findings and to approve the report on its final meeting. A Concepts, Coordination, and Integration Group (CCI) served to generate concepts for evaluation by the appropriate task group, to coordinate the various activities as the study progressed, and to integrate the findings into the *Overview* to which this is the preface. The CCI Group was aided by an Operational Context Group, which served to evaluate the future geopolitical and threat environment, and the Technology Group, which served to identify and address key technical issues.

The remainder of the study was divided into six technical task groups as follows: Air Technology Group, Ship Technology Group, Weapons Technology Group, Radio-Electronic Battle Management Group, Human Factors Technology Group, and the Sustainability and Logistics Group. Each of these six task groups was responsible for gathering information on all technologies falling within their areas of responsibility. The chairman of each task group was a member of the CCI Group. Therefore, the vital function of coordinating findings within a common design envelope was accomplished during meetings of the CCI Group and in three plenary sessions involving the study leadership and a cross section of the participants.

A total of 106 scientists and engineers representing the full spread of technologies considered relevant to the design of an aircraft carrier and its embarked air wing were identified, approved by the National Academy of Sciences' Commission on Physical Sciences, Mathematics, and Applications and the Academy's Executive Office, and, after satisfying the Academy's bias and conflict of interest procedures, were assigned to one of the ten organizational groups. To each of these groups the Navy was asked to assign a liaison representative, himself an expert in the work of his assigned group. Rear Admiral David N. Rogers (OP-05B) served as liaison representative for the Secretary of the Navy, the Chief of Naval Operations, and the Assistant Chief of Naval Operations for Air Warfare (OP-05).

Beginning with an organizational meeting of the full study group on March 20, 1990—following a go-ahead from the Secretary of the Navy—the task groups met for a combined total of 112 days. In addition to extensive documentation, informational input to the groups was provided through a total of 368 invited briefings. To gain firsthand experience, a total of 70

study participants spent 24 hours on an operational carrier at sea, and about half of the study group visited Newport News Shipbuilding to see a carrier under construction. These visits proved of extreme value to the study process.

This *Overview* represents the summary findings of the entire study. It has been reviewed and approved by the Advisory Council, by the Naval Studies Board, and by five independent reviewers assigned to the task by the Academy's Report Review Committee. The more detailed findings and considerations from which the *Overview* was drawn will be distributed separately under the title *Future Aircraft Carrier Technology. Volume II: Task Group Reports*. Volume II will be classified.

Finally, the National Academy of Sciences and its Naval Studies Board would like to acknowledge, with deep appreciation, the total cooperation of the United States Navy during the course of the study. The Assistant Chief of Naval Operations for Air Warfare (OP-05) and his immediate staff bore the brunt of the support required by the study, and that support was always provided in an efficient and timely manner. We wish to thank the liaison representatives who not only helped in identifying and arranging informational inputs, but also lent their own experience and expertise to the study process. Special thanks are due to the captain and crew of the ABRAHAM LINCOLN (CVN-72), the NIMITZ (CVN-68), and the JOHN F. KENNEDY (CV-67) for extensive briefings and tours during very busy operational schedules. Senior officials of the Newport News Shipbuilding Corporation are also due special recognition for providing detailed insight into the design, building, outfitting, and launching of an aircraft carrier. We are also indebted to the many briefers who took time from their busy schedules to share information with the study group. Lastly, our deepest gratitude to the scientists, engineers, and operational experts who labored long and hard over a problem more complex than originally anticipated.

Robert J. Hermann
Study Director

CONTENTS

PART ONE

INTRODUCTION, SYNOPSIS, AND RECOMMENDED PROGRAMS

3

1

INTRODUCTION

As a maritime as well as a continental power the United States has traditionally insisted on freedom of the seas, and we have protected that freedom and projected power ashore from the sea throughout the 20th century by using strong maritime warfare forces. With the internationalization of the Western economies our connections to overseas sources of economic strength and support have become even more important to our own welfare and security.

Since 1942 carrier-based aviation has been central to the exercise of our naval power. It has been the most called-upon initial instrument to exercise military power in instances when the President has needed such an instrument. In four wars and many lesser missions of deterrence and presence it has been a major base for air power brought to bear against the opposition. A review of the position of aircraft carriers during the National Research Council's study of the Navy's future[1] showed that despite—in fact, because of—changes in the world military power balance that will be reviewed later, it can be expected that in the future carriers will be called upon continually to fulfill this important national role and mission.

Advancing aircraft, weapon, and ship technology will be available both to the United States and to other nations that may oppose our forces. Such technology can lead to significant changes in the configurations and design of sea-based aviation and supporting forces, increasingly so as time goes by. There are three main periods when naval systems R&D programs, within anticipated resources, can be expected to lead to technological advances mature enough to warrant their incorporation in carrier systems. In the near term, 1993-2005, technologies that have essentially been developed can be applied. In the mid term, 2005-2020, technologies for which the approaches are now reasonably well understood or in early experimental phases, but for which the applications have yet to be developed, can become available. In the long term, beyond 2020, technological advances currently conceptualized but never applied, and for which essential elements of the

[1]See the Navy-21 study, *Implications of Advancing Technology for Naval Operations in the Twenty-First Century*, a report of the National Research Council's Naval Studies Board (National Academy Press, Washington, D.C., 1988), pp. 44-48.

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phenomenology remain to be learned, might be brought into being with continuing support.

The currently visualized carrier retirement and acquisition program is shown in Figure 1.1. The schedule illustrated could change. Depending on the particulars of a technology and its applications, many new technologies can be incorporated in the carrier force through modernization of existing ships, while any of them can be incorporated in the designs for new ships. In some cases, it may be desirable to pursue a technological application with a particular ship acquisition in view, but that is not necessary. The advance of carrier system technology is linked to its availability rather than to any particular ship acquisition program.

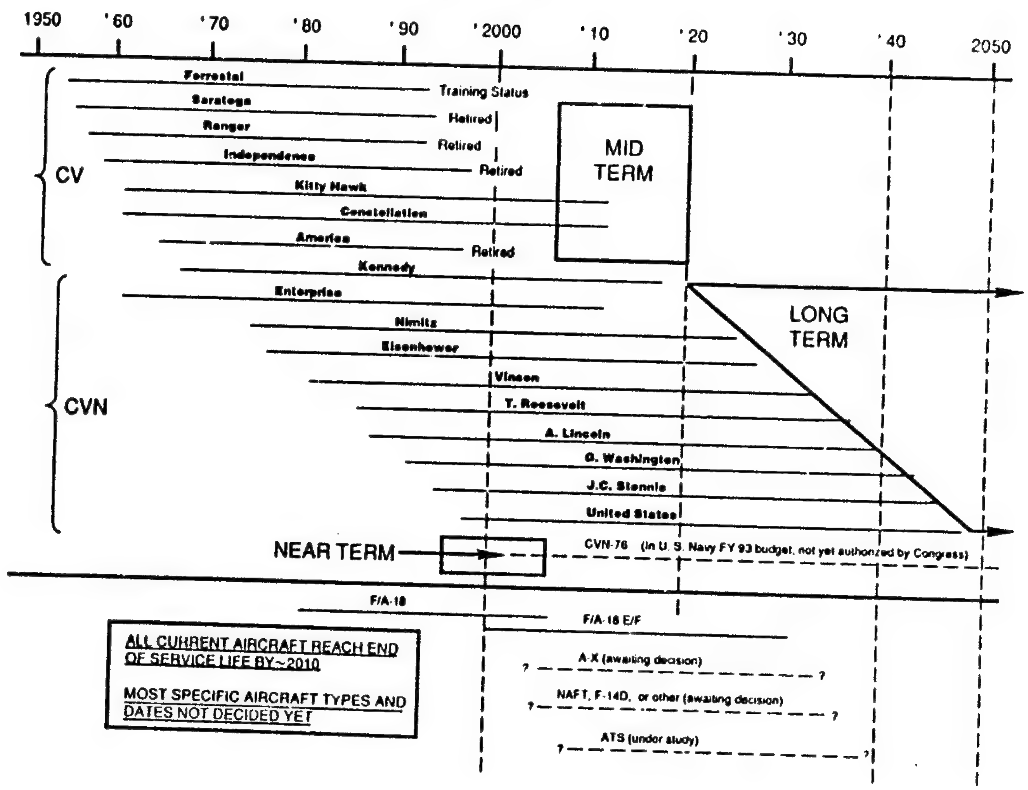
CHARGE TO THE NAVAL STUDIES BOARD

To obtain a clearer view of the likely and desirable progression of carrier system technology, the Congress asked the Secretary of the Navy to have the present study performed. In his letter asking the Naval Studies Board to perform this study, the Secretary of the Navy asked for

- a survey of applicable technologies,
- an assessment of risks associated with the development of these various technologies,
- estimated magnitude of the costs of developing these technologies for future aircraft carriers, and
- the likely impact of the technologies on aircraft carrier design.

The Conference Report on the Defense Authorization Act for Fiscal Year 1990 asked for a study to "identify and understand how evolving, emerging, and desired technologies might be combined and/or targeted to ensure the nation continues to enjoy superiority in the technology of sea-based aviation. . . . [and] . . . an integrated technology plan for the evolution of aircraft carriers in the first half of the twenty-first century." It also posed questions as to the implications of eliminating catapults and arresting gear, the possibility of achieving greater carrier speed from optimized hull design and increased power, and the potential for a mobile sea base from which all kinds of aircraft could operate. The congressional conference report repeated the request for an "integrated technology plan."

Figure 1.1 Periods of opportunity for carrier evolution.



THE CURRENT STUDY

This *Overview*, together with *Volume II: Task Group Reports* from which it is drawn, responds to these questions. It reviews the critical threat, mission, and technology issues affecting carrier design, and it explores the technical, operational, and cost implications of several carrier design options and their costs. The study has identified many choices that must be made about the design and operating characteristics of the entire carrier system. A prudent near- to mid-term course of action is recommended that accounts for appropriate balance among different ways of resolving the critical design issues in order to benefit from the technological opportunities available to improve the carrier system in a resource-constrained environment. A carrier-oriented R&D program is recommended that can make available to the Navy several options for carrier- and sea-based-aviation system designs during the mid- to long-term periods of carrier evolution.

In performing this study, the Naval Studies Board considered no issues to be immune from examination. However, the fact that a question is raised, explored, and leads to some systems concepts does not necessarily imply that all such concepts are advocated as conclusions or recommendations of the study.

A synopsis of the study (Chapter 2) follows, briefly summarizing the main elements of the operational context and threat, potentially available future technology that will affect the carrier and related systems, carrier design drivers and their implications, the issues raised by the joining of potential future threats and technological advances, and the carrier options that were identified in the course of the study.

Recommended directions of evolution of the future carrier force and a summary of recommended, carrier-oriented R&D programs are presented in Chapter 3.

Part Two of this *Overview* reviews the assumptions and premises guiding the study and discusses the background (Chapter 4), the operational context and threats (Chapter 5), the technology (Chapter 6), carrier design drivers (Chapter 7), and the issues and the options (Chapter 8) in more detail. Discussions of sea-based platforms (Chapter 9) and carrier-system-related R&D (Chapter 10) complete Part Two, which provides a comprehensive background for the conclusions and recommendations presented in Part One. The full details of the individual parts of the study are contained in Volume II.

2

SYNOPSIS

OPERATIONAL CONTEXT FOR FUTURE CARRIERS

The carriers being considered now will probably be in the force beyond the middle of the next century; some of those acquired to replace the NIMITZ-class ships may still be in operation at the end of the century. The "presence" and warfare missions of the carriers and their aviation are not expected to change significantly, but the operational context in which they will carry out missions and the means for doing so will change considerably.

Specific elements of our overseas posture, including overseas military bases, are becoming more uncertain or insecure. The Navy provides the only force that can establish a visible, persistent presence in a troubled or threatened area for stabilization, deterrence, or rapid response to clear threats to U.S. interests with military force, without impinging on the sovereignty of any nation in such an area.

Although the U.S. security emphasis has shifted to the Third World, the retained military might of the Soviet Union remains a continuing, latent threat to the United States and is therefore of concern to the Navy. It could reemerge as a major national concern very rapidly. The Navy must remain prepared to meet Soviet naval warfare elements having attack capability with short tactical warning. This requirement has not been changed by the current Soviet withdrawal from confrontation in Europe.

Third World countries are acquiring military capabilities that can seriously threaten U.S. naval forces at sea and that can effectively oppose strike warfare by naval aviation over land. These capabilities are summarized in Table 2.1 and elaborated in Chapter 5.

Although the war with Iraq suggested that some Third World countries may not now be able to use all their advanced equipment effectively, they can be expected to learn or be taught how to do so over the lifetimes of the ships being considered. Also, Iraq's inability to capitalize on its advanced equipment must be attributed perhaps in large part to the effectiveness of U.S. systems and their use.

Current proposals to limit the levels of arms sales to Third World countries will take significant time to implement. If accepted they may be expected to slow the growth of military capabilities of those countries, but

TABLE 2.1 Overview of Third World Military Capabilities, Current-2010

CAPABILITY	MAIN COUNTRIES HAVING	MAIN COUNTRIES PROVIDING
Modern tactical aircraft in significant numbers (stealth technology in demand and appearing to some extent in designs)	All in Middle East and Southwest Asia; India; Pakistan; China; Latin America; Japan; North and South Korea	U.S.; USSR; France; U.K.; some indigenous
Anti-ship guided missiles; potentially stealthy; fast maneuvering	70 countries	France; U.S.; USSR; China; others
Modern, quiet non-nuclear submarines (44 now; 84 near term)	India; Pakistan; Egypt; Israel; South Africa; Taiwan; China; 7 Latin America; South Korea; Middle East; Southwest Asia; Southeast Asia; others considering	Germany; U.K.; France; Sweden; the Netherlands
Mines & advanced torpedoes	All that have submarines; 21 countries with naval mining capabilities, some modern	Same as above, plus USSR, U.S., others
Chemical weapons	14 countries have capability; 10 more developing it	Germany; Brazil; basic chemicals easily available

Ballistic surface-to-surface missile (SSM), range >200 mi; potentially, maneuvering warheads	China; Brazil; Israel; Libya; Egypt; Saudi Arabia; Iraq; Iran; India; Pakistan; North and South Korea	China; Brazil; USSR; North Korea; others; some indigenous
Nuclear weapons	Tested weapon/device: China, India; Assumed: Israel, Pakistan, South Africa; possible soon: North Korea, Brazil, Argentina, others	Related help attributed to China, Germany, Brazil (West is not vigorous in controlling relevant technology)
Laser weapons vs. sensors & people	Any can build laser for blinding; range finders common	General technology flow; USSR & NATO countries working on systems
Modern C^3I & targeting, including space-surveillance capability	All have communications systems; Japan, China, India, Israel have satellite launch capability	USSR, France selling ≤ 10-M-resolution space data
Modern ground forces (tanks, artillery, helicopters)	All Middle East and Southwest Asia; China; Pakistan; India; South Africa; North and South Korea	U.S.; U.K; France; USSR; Italy; Germany
Modern air defense weapons/systems (especially shoulder-fired)	All Middle East and Southwest Asia; India; Pakistan; Japan; China; North and South Korea; many others	U.S.; USSR, France; U.K.

NOTE: Figures include Iraq, which, although now destroyed, can be expected to rebuild by 2010, with help from outside.
SOURCE: Summarized from unclassified data published by ACDA, Jane's, IISS, and USN.

due to indigenous manufacture and covert arms shipments, not to stop that growth in the long run.

The diffusion of threats and possible combat areas from the USSR to the Third World will mean an increase in operations in littoral or coastal regions where the U.S. fleet will become more accessible to proliferated, opposing tactical aviation and antiship weapon systems. The battle for air supremacy will move away from the Soviet-oriented three-tiered open ocean scenario (outer air battle, area SAM defense, close-in ship self-defense) to become a mixed battle involving integrated use of SAMs and fighter aircraft, and ship self-defense. Guided weapons of all kinds, stealth, and operations at long range from sources of opposing fire will become the norm in both threat and carrier operations.

Over its lifetime the carrier system will have to be prepared to work with and contend with a flexible array of capabilities in what is becoming an increasingly unstable and transient set of world political and economic relationships. All the indications are that the Navy and the naval aviation system will have to continue to strive for the best technological capability that can be achieved.

THE CARRIER SYSTEM

The carrier is part of a complex maritime warfare and naval aviation "system of systems" that includes sea-based aviation; the ship as the base; the defenses of the ship and the fleet of which it is a part; the targeting, C^3I, logistic, and support systems for all of the functions; and the personnel and training to operate and maintain them. The system components may be part of the aviation complement of the carrier; they may be part of the carrier itself; they may be part of the fleet that accompanies the carrier; or they may be land- or space-based, even though they are part of (i.e., "organic" to) the seaborne aviation system. The carrier system also has many links to, and often works interactively with, forces of the other armed services, under the command and control of a regional commander-in-chief (CINC).

Like any major system, all the components of the carrier system are tied together in complex feedback loops. **Significant changes in one part of the system must affect the distribution of functions and costs in the others.** Some of the issues that will drive carrier design must be resolved in other parts of the total system as well as in the design of the carrier.

FUTURE CARRIER SYSTEM TECHNOLOGY

The potentially most influential technology candidates for use in future carrier systems are listed and their significance and possible dates of appearance are summarized in Chapter 6.[1] Summary Table 2.2 lists some of them, roughly (but not altogether) in the order in which they come into play in the carrier design; this listing may be considered as part of the data base needed to appreciate the system design issues and carrier options to be presented shortly .

Each area of technology will have associated costs, risks, and payoffs. The technologies listed in Table 2.2 are the ones expected to have the largest payoff in improving carrier design and the capability of sea-based aviation. As a general matter, and following from the definitions of relevant time periods given in Chapter 1, the farther in the future Table 2.2 shows the initial availability of a carrier- or carrier-system-related technology to be, the higher will be the technical risk in trying to achieve it, and the higher will be the total cost of achieving it, relative to nearer-term systems.

CARRIER DESIGN DRIVERS AND THEIR IMPLICATIONS

There are a few main "drivers" of future carrier design. Their impact is noted here and the issues they raise are discussed in the next section, "Carrier System Options and Issues."

1. *Trends in aircraft technology* determine the size and influence the design of the flight deck and therefore determine much about the size and design of the carrier as a whole. These trends are moving in three directions:

a. The geographically driven need for longer-range strike aircraft and the threat-driven desirability of longer standoff from hostile shores lead to larger, heavier CTOL aircraft that can outgrow the current NIMITZ-class carrier. The critical aircraft systems in this growth trend are the ones that must replace the aging E-2C, S-3, and EA-6B to provide tactical support. To accommodate to the growth trend starting

[1]Overall RDT&E budget devoted to carrier-system-related efforts, except for variations in aircraft full-scale engineering development, are not expected to decline materially. If they do, the Navy will have to change priorities accordingly.

TABLE 2.2 Some Potentially Important Future Carrier System Technologies

APPLICATION	TECHNOLOGY	WHEN
Combat aircraft trends affecting carrier design	• Increasing range and payload performance with stealth characteristics in CTOL aircraft • STOL characteristics from aerodynamic design and vectored thrust (with 10-12% wt. penalty for ~30% reduction of landing speed) • High-performance fixed-wing STOVL aircraft in F/A-18 wt. class (~5% wt. penalty beyond carrier-capable CTOL, in single-engine version; twin-engine implies changed rules or more penalty)	• Now to mid term • Mid term • Mid term
Support aircraft trends affecting carrier design	• Advanced, multi-sensor integrated avionics, including counterstealth • Very high altitude (100,000 ft), long endurance (indefinite, with spacecraft reliability and in-air refueling) UAVs (HALE) • High-performance rotorcraft (tilt rotor; folding rotor; etc.)	• Now through mid term • Mid term • Near to mid term
Aviation and carrier armaments affecting carrier design	• Advanced guided strike warfare weapons affecting magazines, targeting & air delivery systems, aircraft carrier mission and mix, and so on) • Improved weapons for carrier self-defense, including high-speed, maneuverable counterstealth missile systems; improved gun systems; improved integrated ECM and decoying • Hypervelocity kinetic-energy and laser weapons for carrier self-defense • Ship torpedo defense • Anti-tactical-ballistic-missile (ATBM) defense • CL-20-based, and insensitive, explosives and propellants	• Now to mid term • Now to mid term • Mid to long term • Near to mid term • Mid term • Near to mid term

Carrier design features	• Signature management • Modern, delayed cavitation propellers and quieter machinery • Skijump flight deck for assisted takeoff • Enhanced passive torpedo protection • Advanced armor • "Instrumented ship" for damage isolation and control, and maintenance • Fiber-optic internal communication and weapon system networks • Electric catapults and arresting gear • Electric drive • Improved night operations capability • Very large semisubmersible hull forms (e.g., SWATH & variants)	Now through mid term • Now • Mid to long term • Near to mid term • Mid to long term • Long term
Radio-electronic/acoustic battle management advances for survivability and carrier operations	• Advanced sensors • Carrier-specific, functionally integrated sensors and C^2 • Planar array, electronically scanned radars on ships & aircraft carrier • Advanced computing in small packages • Cooperative engagement and multi-sensor integration • LPI/LPD communications; high-capacity multimedia data links • Advanced displays	Now through long term • Near term • Near to mid term • Near term
Human factors, supportability, sustainability	• Habitation modules for crew support efficiency • Advanced selection, classification, and assignment techniques • Computer-based logistics, support, and operating systems, with automation, all designed for greater efficiency, effectiveness, and reduction of personnel • Flight operations and aircraft carrier turnaround as a production process • All-electric "yellow gear"	Now through mid term • Mid term

from the current nuclear-powered aircraft carrier (CVN), the advanced aircraft landing speeds can be reduced; catapult and arresting gear can be extended and operating margins reduced; a small skijump can be added to the forward part of the flight deck; the ships can be made larger; or more of the functions can be carried out by offboard systems. Any of these solutions conveys unique benefits as well as imposing penalties and costs, which are different in each case.

b. The potential availability of high-performance powered lift aircraft, both fixed-wing and rotorcraft, results from continual increases in engine thrust-to-weight ratios and reduced structural weight fractions. The convertible, high-performance rotorcraft could perform some of the advanced tactical support (ATS) functions on large carriers, and the fixed-wing aircraft could perform many of the combat functions that are based on large carriers, and on amphibious assault ships. Although they will carry penalties as well as opportunities, as indicated in the detailed tables of technological advances presented in Chapter 6, both classes of aircraft also open the possibility for less capable but versatile smaller carriers without catapults and arresting gear that can be useful in complementing the large carriers and in some independent operations.

c. Unmanned aerial vehicles to fill key supporting roles, and especially high-altitude, long-endurance aircraft that have spacecraft reliability and that can be aerially refueled from the carrier. Such systems will have application in controlling carrier growth.

2. *The need to enhance survivability of the carrier as threats become more capable and more severe.* The most severe threats will be stealthy, high-speed, sea-skimming missiles using terminal maneuvers; steep-diving missiles leaking through the outer defenses; ballistic missiles with maneuvering warheads; and large torpedoes designed to explode under the ship's keel. Mines will constitute a continuing threat. While the carrier's aviation in the defense role and the other battle group defenses will be to defend against the threat "launchers" and long-range missiles at a distance from the carrier, some of these threats leaking through the longer-range defenses will require greatly enhanced close-in defensive measures inherent in or based on the carrier itself. Survivability can be enhanced by a combination of passive and active means:

a. The main *passive* means include (1) signature reduction that makes targeting more difficult and electronic warfare and deception easier, and (2) enhanced resistance to and control of damage. Reducing signatures requires changes in hull shape, propulsion systems, emitted

signatures including unique ship radars and communications with their antennas, and some aspects of ship and aircraft operating procedures. Improved damage control can be achieved through advanced shipboard sensing and communications, and automation, that enhance knowledge of damage and responsiveness to it. *Greater resistance to underkeel torpedo damage is the most severe design requirement* (see Volume II, Ship Technology and Weapons Technology Group Reports); it demands space and thus affects ship layout, especially of magazines, or ship size.

b. Increased *active* defense, including self-defense of the carrier and improved battle group defense systems, would entail AEGIS-like radars on the carrier to carry out functions of the current radars and to extend the engagement envelopes (and would remove a set of unique carrier signatures in the process); new planar array electronically scanned radars for horizon scan and close-in defense; electronic countermeasures and decoying systems on the carrier; vertical-launch missile bays aboard the carrier to provide more firepower; active torpedo defense aboard the carrier; mine sweeping in areas the carrier must transit; incorporation of the radar improvements in other ships of the battle group and improved integration of the defenses on the carrier and in the entire battle group, with requisite attention to sturdy, low-probability-of-intercept communications to enable the integration.

These are near- to mid-term problems and solutions. Clearly, all the above measures interact, and they can be applied selectively. Overall, the active defense improvements tend to add less cost to the carrier system than do the passive defense measures, because they require less redesign of the carrier and they can be undertaken without forcing carrier growth. However, many useful passive defense enhancements can be incorporated in carriers of current size for modest cost.

Advanced directed-energy weapons (high-powered microwave weapons, lasers, particle beams) or electromagnetically driven hypervelocity kinetic-energy weapons (railguns, coilguns) can be advantageous in carrier defense. However, all face severe developmental and practical problems that will delay their application until the mid- to long-term periods, and their availability will depend on continued R&D support. It will also be useful, subject to world developments and to arms control and policy restraints, to make available the capability to deploy low-yield nuclear warheads to counter nuclear-armed attacks and possibly for other special defense applications if the need should arise. Depending on the combat conditions

anticipated, the development can be straightforward or very demanding technically.

3. *Advances in the areas of propulsion and management of large amounts of usable power* can enhance ship survivability and efficiency and make available an array of important new capabilities:

a. The current generation of reactors is extremely reliable but aging in technology; advanced, higher-power-density reactors, if they were available, could lead to significant volume savings that might be applied to the volume needs of ship active and passive defense. Also, attention in reactor R&D, design, and operation can be given to extending the life of the fuel rods in reactors, increasing the interval between refuelings and thus enabling significant operating and support cost savings. The two directions may or may not be mutually exclusive; one purpose of a reactor R&D program would be to reconcile them to the extent feasible.

b. Advances in energy management and electric power transmission and conditioning systems are necessary for electric drive, electric catapults and arresting gear, and electrodynamic armor—all mid- to long-term contributions to carrier survivability; they would also be necessary for operation of the directed-energy and electromagnetically driven hypervelocity kinetic-energy weapons.

4. *Advanced logistics and personnel support systems.* These include computer-supported design and operation of support and logistic systems; application of production system concepts to aircraft operation and turnaround; application of "instrumented ship" damage control concepts to condition-based ship maintenance; changes in habitability, provisioning, and resupply concepts and doctrines; modern personnel selection, classification, and assignment techniques; imbedded training; and many other support-oriented measures that have the potential to increase sorties, reduce personnel, make volume available for other purposes such as sustainability or survivability measures, and make it possible to insert new technologies without increasing manning requirements.

CARRIER SYSTEM OPTIONS AND ISSUES

The Naval Studies Board's careful consideration of the main factors affecting carrier design and of the possibilities for resolving the problems they pose has led to description of four basic options for future aircraft

carriers and carrier systems. The options are presented here to show the range of possibilities that was considered in the study. Review of the options and their implications led to the board's recommending the courses of action presented subsequently:

1. *An advanced NIMITZ-type carrier, within the NIMITZ-size envelope (overall dimensions).* The ship would be changed to the extent feasible to meet some of the most severe threats and engineering problems foreseen and to capitalize on some of the most important of the technological opportunities in the offing. This would be the least expensive option; the cost could range from that for a current NIMITZ-class ship up to 10 to 15 percent more, depending on the extent of internal change and new passive and active protection incorporated. Survivability enhancement would depend on compromises in the use of space from other functions (such as reduced magazine volume or a smaller air wing) for enhanced passive defense, and on capacity to incorporate enhanced active self-defense systems.

2. *A new, large monohull.* This ship would offer more scope for change, including an air wing with larger and heavier aircraft having more range and payload capability and more ability to defeat stealthy attackers, enhanced ability to reduce the ship's signature that permits targeting by opposing forces, improved underkeel torpedo protection for the carrier, and more self-defense. This ship would be larger than one in the NIMITZ class, in a range from 100 to 400 ft longer. Depending on the extent of changes incorporated, it would displace 105,000 to 215,000 tons. In particular, one version of such a ship might be a "stretched NIMITZ", 125 ft longer and displacing 110,000 tons. This ship might cost 10 percent more than a NIMITZ-class ship not including other changes such as significantly upgraded active defenses and nonrecurring costs associated with design upgrade and drydock extensions. At the other extreme, a ship, including full allowance for the aircraft- and survivability-related changes reviewed (both active and passive defenses), could reach 1,500 ft in length, displace 215,000 tons, and cost as much as 100 percent more than a NIMITZ.

3. *A large semisubmersible ship.* This ship could offer the most extensive opportunities for signature reduction, and preliminary considerations suggest that it might have the greatest inherent damage resistance of all the options. It would have a rectangular flight deck of approximately the overall dimensions of the NIMITZ flight deck, configured to operate with all aircraft in the hangar decks except when being launched

or recovered, and ballasted to run with the propellers on the submarine-like hulls at about a 125-ft depth but designed to reduce ballast and draw about 40 ft to enter harbors. The ship would displace about 325,000 tons, empty, and about 660,000 tons with ballast and the hulls at running depth, and it would require four times the power of a NIMITZ-class carrier to achieve 25 knots. This is slower than the monohulls, but a skijump could reduce wind-over-deck requirements; deployment time would still be affected. This ship would represent a very long extrapolation from current experience with semisubmersibles, so that its design and development could be expected to be fraught with unknowns and the unexpected. Based on extrapolation of costs from a combination of carrier and submarine construction costs, it might cost three times as much as a NIMITZ-class carrier, and unanticipated engineering problems could raise this to as much as four times the cost of a NIMITZ-class carrier.

The above three alternatives would be able to operate a carrier air wing of 85 to 90 aircraft, having the multi-capability mix of today's air wing, under different conditions of in-hangar or on-flight-deck storage, servicing and operation, self-defense, and offboard support for the different ships.

4. *An LHA/LHD[2]-sized carrier or one somewhat larger (e.g., 40,000 to 50,000 tons).* It would be designed to operate an air wing of up to 30 new STOVL fighter/light attack aircraft in the F/A-18 weight class with supersonic cruise capability, or a smaller-sized air wing including a mix of the STOVL fighter and high-performance, convertible rotorcraft for antisubmarine warfare (ASW) and other supporting roles. It would not have catapult and arresting gear. Survivability, magazine capacity, onboard maintenance capability, and independent operating capability would be limited in comparison with current CVNs. Cost would be about 60 percent of the cost of a NIMITZ-class ship. This ship would be planned for use in a complementary air defense and ASW role with the large carriers; in support of amphibious operations; or by itself in less threatening environments. *The value and viability of such a carrier would be contingent on development of the new aircraft. However, the new aircraft themselves would also be useful on the large CVNs, and on current LPH/LPD[3]-type ships,*

[2]The largest class of amphibious assault ships.
[3]Classes of amphibious assault ships.

so that their development need not be contingent on a decision to develop the small carrier.

For a ship itself, cost is roughly proportional to displacement, with some economies of scale in going to larger ships. The rough cost estimates given for the different carrier options are based mainly on ship weight, and the ranges are based on considerations of uncertainty or risk in the designs. The cost associated with including a particular technology in the carrier system for a carrier of a given size cannot easily be forecast without particularized design studies, because many technological exchanges may accompany the incorporation of a single major technological advance and this may lead to more or less overall cost of the carrier and the system.

Some key issues regarding the overall desirability of the different options are as follows:

- Although the Soviet threat has subsided at least for the moment, the next-generation carrier and those of succeeding generations will have to contend with potential opposition, including forces from many countries that even now are acquiring advanced technical and combat capabilities that can stress the current carrier system to its limits. The ships may also have to deal with a resurgent Soviet threat, from uncertain directions, on short notice.
- Most potential solutions to the problems imposed by the new operational context and the increasingly capable threats against U.S. carriers tend to cause carrier growth. The growth implied by ensuring enhanced passive underkeel torpedo protection without reduction of air wing and magazine size would be the determining item for future carrier size; if that growth were accepted there would be adequate ship space for the larger and heavier aircraft that might otherwise cause ship growth. There would also be more ample space for augmented passive and active self-defense of the ship.
- A larger carrier can thus be made more likely to survive, and larger aircraft will be more capable and will give the system more striking and defensive power at longer range. Growth of the ship can be restrained by forgoing some performance gains of onboard aviation and accepting more risk of damage to or loss of the ship.
- The criticality of the ATS function (including surveillance and targeting, airborne early warning, antisubmarine warfare, and electronic warfare) as a driver of carrier size depends on where the

problem is partitioned and how the support burden is divided. The carrier system will be able to carry out some significant set of these tasks by itself, and then the battle group will have to be augmented by outside assets for the purpose, as indeed it is today. The choices for those assets include space-based systems; land-based aircraft where geography and base posture permit; and possible unmanned very high altitude, long-endurance (HALE) aircraft with extremely sturdy data links to the ship. In the HALE case, the functions that are now carried out by the aircrews aboard the support aircraft would be performed on the ship. Each approach has advantages as well as disadvantages. Availability of the offboard assets when needed will be a major concern for battle group commanders. Solutions lie in the direction of making such assets "organic" to the battle group, under the commander's control, wherever they are based. The revised system configurations would not only be effective in all the situations the future carrier might encounter outside potential conflicts with the Soviet Union, but they would also be well designed to deal with a potential, resurgent Soviet threat including land-based aviation. This could be a reasonably safe position hedged against future uncertainty.

- If accommodating all of the growth pressures were to lead to a new, larger class of ship, an important concern would be the concomitant need for new port facilities, especially drydocks. The outlay for new facilities could be on the order of $2 billion to $3 billion for new graving dock and drydock facilities on both coasts. Other arrangements for support and servicing could be made, but they would entail operating and facilities costs as well. The largest ships contemplated in the above array of options may need support systems that require them to enter port only rarely, much as supertankers operate today. The "stretched NIMITZ" could be built in the graving dock on the East Coast, but lengthened drydocks would be necessary for overhaul and repair.
- Advancing technology will make available many improvements in the design of *any* carrier—such as some of those in the signature and active defense areas, damage control, advanced logistics, maintenance, and personnel support areas—that should be incorporated because they will improve survivability, improve combat power, reduce personnel requirements, and enhance operating efficiency and sustainability.

- Design changes to make a carrier more efficient and increase its damage resistance without growth could add or reduce costs, in some combination that will not be known until a new design is undertaken. Many potential capital cost increases will be more than offset by reduced life-cycle costs, requiring the budgeting and planning system to exchange near- for far-term savings. As is so often the case, decisions may have to be made to accept larger "front-end" costs if the desired, much larger "downstream" cost savings are to be gained.

LARGE SEA-BASED PLATFORMS—A SPECIAL CASE

In asking the Secretary of the Navy to have this study performed, Congress also expressed interest in an exploration of the possibilities for building large platforms from which all manner of aircraft, rather than those especially configured for current types of aircraft carriers, could operate.

One option available for such a system is a large platform, with a size, for example, on the order of 9000 by 900 ft, based on a combination of deep sea oil rig and hollow-column-plus-platform modular construction. This platform, which would be the quasi-permanent seaborne analog of a tactical air base on land, would be able to operate any aircraft ranging from land-based fighters to large military transport aircraft. Another option is a semisubmersible ship, such as that described above, about 2000 ft long and configured to operate any combat aircraft that can operate within the standards established for operation from carriers or from runways with bomb craters, and tactical transport aircraft like the C-130.

It is estimated roughly that the "island" option would cost from $4 billion to $8 billion, based on extrapolation of estimates for offshore airports and allowance for military specialization and lack of experience with assembled structures of that scale. The ship option would cost in the $40 billion to $55 billion range, based on extrapolation of the estimate for the large semisubmersible carrier option. The cost difference between the two platform options would buy mobility. The large island could be moved only very slowly (about 2 to 4 knots, if indeed it did not have to be disassembled and reassembled in another place); assembling it, stabilizing it against wind and ocean current pressures, and keeping it flat and rigid enough for aircraft operations would pose difficult engineering problems. Calculations based on SWATH design principles indicate that the ship version could move at about 20 knots in a practical design, but it would face all of the same

engineering problems and unknowns that the 1100-ft semisubmersible carrier would face.

Missions and operating conditions for platforms such as those described here have yet to be defined clearly. If either platform were used very far off a hostile shore, tactical aircraft range could become a problem. If used in close, neither would have the mobility advantages of a carrier, but both would have most of the physical and many of the political vulnerabilities of a land base. Moving such platforms could require extra-long journeys because the platforms could not easily move through many straits connecting the major seas and the oceans.

This first-order examination led to the judgment that the large sea-based platform concept is different in kind from the aircraft carrier concept and would serve different functions. The ship version of a large floating platform is questionable on the basis of cost. The large floating base would be akin to having a fixed, quasi-permanent overseas tactical air base, moved offshore because it is not wanted or cannot be accommodated onshore. A carrier is designed to carry out missions requiring mobility and the ability to appear and operate in particular geographic areas and then to shift to others on short notice. The two concepts are not alternatives for each other, and each needs evaluation in its own frame of reference. This report is concerned with carriers and does not deal with the large sea-based platform concept any further.

RECOMMENDED PROGRAM

RECOMMENDED COURSES OF ACTION

Desirable future CTOL aircraft range and payload characteristics and more potent threats facing the carrier system in the future give many reasons for the carrier to increase in size from the current NIMITZ-class ship to one that is longer and of larger displacement. These reasons have been sketched above and are discussed in more detail in Part Two. The "stretched" NIMITZ-version of such a larger carrier, 125 ft longer than a NIMITZ and displacing 110,000 tons, appears especially attractive in this respect because it would not have as large an impact on the infrastructure as other designs for larger ships, it would give a measure of added underkeel torpedo protection, and it would accommodate new aircraft of the higher weights being contemplated. However, the "stretched" NIMITZ would not provide enough additional torpedo protection to permit foregoing added active defenses so that the total cost of the ship could grow to as much as 25 percent more than a NIMITZ. Other changes can be made in the carrier design that will greatly increase effectiveness and efficiency at lesser cost within the NIMITZ-class size envelope. These opportunities should be seized at all stages when the technologies to do so can be applied. R&D programs are recommended to provide additional options for improved effectiveness and efficiency in the later mid-term to long-term periods, when carrier system needs may change significantly.

The advisability of pursuing a dual-track carrier development program that includes the large (NIMITZ size or larger) and small (about LHA/LHD size) carriers has also been considered.[1] The smaller carrier would *require* development of a new family of powered lift aircraft. However, since such aircraft can be valuable for carriers of any configuration and size, the decision to develop them should not be tied to any particular carrier design. The smaller carrier, viewed in its own context, would cost nearly two-thirds

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[1]LHA/LHD is used simply as a representation of the carrier size under discussion. Carrier-cost is based on $19 per lb (compared with $18 per lb for the NIMITZ). Average aircraft spotting factor of 3,000 ft^2 was assumed to allow maneuvering room, parking space, etc. Based on LHA deck size of 850 ft by 108 ft, allows about 30 aircraft of FA-18 size on the carrier.

as much as the large one, while embarking about one-third as many aircraft. More such carriers could establish "presence" in different places simultaneously within a given budget, but with less fighting power at each location. While there would thus be advantages in having a smaller ship with different capabilities, this study did not identify enough advantage for the smaller carrier to recommend it as an alternative or as a parallel system for acquisition. However, since its attributes, including both opportunities and liabilities, would clearly differ from those of a large carrier, more should be learned about it to be able to judge whether the smaller carrier might become a desirable future option.

Following is the strategy that the study group recommends for future carrier system development and acquisition:

1. Plan the near-term carrier and the early mid-term carriers so that they stay within the same size envelope as the NIMITZ class and use the NIMITZ hull form. Attention should be given to modular design so that valuable improvements in subsystems can be easily and quickly incorporated at appropriate intervals as they become available from R&D. It is estimated that a carrier with the modifications described immediately below may cost 10 to 15 percent more than a NIMITZ-class carrier as one exists today.

2. Concentrate on improving *active* carrier self-defense, including the essential radar changes summarized above and elaborated in Part Two, which also support signature reduction and deception; missiles in vertical launch bays; improved close-in gun systems and self-defense missiles; shipboard torpedo and mine defense; integrated electronic countermeasures (ECM) and decoying; and improved integration of all the shipboard defense systems with each other and with the other battle group defenses.

3. Incorporate enhanced *passive* defense to the extent feasible with modest cost, including:

a. Reasonably achievable signature reduction, especially considering radar cross section (RCS) and its compatibility with electronic warfare and decoying measures, and noise and wake reduction through propeller improvements and machinery quieting;

b. Design for greater survivability, including selective application of improved armor and ability to absorb hits with less resulting damage;

c. Improved damage control, through internal distribution of sensors, controlled ventilation and cleaning system that can deny oxygen

or flush toxic substances as needed, appropriate automation, and a sturdy internal ship communication system.

4. Incorporate logistics- and personnel-oriented advances in technology and design characteristics (Part Two) to achieve the potentially available operating efficiencies and personnel reductions; pay special attention in doing so to "capturing" the ship interior volume freed by reductions in personnel to make it available for other purposes. The potential personnel savings and operational efficiencies achievable from application of modern personnel and logistic engineering can be translated into increased sortie rates, more effective sorties, and gains in ship sustainability and survivability, as well as in reduced operations and support (O&S) costs. *Achieving these gains will require attention from the top levels of the Navy where overall carrier system characteristics are specified, accepted, and verified, since none of the designers, builders, program managers, or commanders at the ship and aircraft subsystem and system levels is responsible for the overall level of personnel on the ship or the cost and effectiveness implications of personnel-related decisions that they may make.*

5. To stay within the NIMITZ-size envelope, adapt existing and near-term aircraft designs for the tactical support area to meet mission requirements imposed by threat evolution to about 2010: e.g., let the enhanced self-defense compensate for the effects of possible shortcomings in long-range airborne early warning (AEW); develop electronic warfare (EW) versions of the A-X when it is defined; explore extending the S-3 airframe or adapting newly available high-performance rotorcraft to improve ASW capability; take prudent steps such as those described in Chapter 7 to enable the ship to operate somewhat heavier aircraft if need be; and improve the battle group's ability to operate in joint modes with shore- and space-based systems. These actions would fill the gap until newer systems could be made available for the mid term and beyond.

6. Pursue a carrier-oriented R&D program to open new options for carrier evolution in the mid- and long-term periods. Although there are many pertinent R&D projects, there is currently no comprehensive R&D program aimed explicitly at improving aircraft carriers. Many of the advances in R&D programs for weapons, aircraft, and smaller ships can have the effect of advancing the carrier and the carrier system, but adaptations become necessary during carrier design and construction. A program of R&D explicitly designed to advance the carrier and the overall carrier system

would include many of the ongoing R&D programs, but it would give some of them more or different emphasis. In addition, some R&D is unlikely to be pursued unless explicitly undertaken for the carrier system.

7. For maximum success in advancing carrier capability, give more attention to *management of the process* by which the R&D and its integration into the carrier system are achieved. Currently, a carrier is built largely by accretion of subsystems and systems from various sources, in a diffuse evolutionary process leading to many *ad hoc* design features. A focus within the Navy, providing concentrated attention but not requiring very high expense,[2] is needed to design, schedule, and modulate the process of carrier evolution so that the planning and implementation of the total carrier system and its progression through the years can be integrated more purposefully, expeditiously and effectively than occurs today. This attention would focus on designing carrier systems to accept change readily; ensuring continual technology insertion at appropriate stages of carrier modification or in new designs; simulating potential technologies in appropriate environments to ensure their feasibility and workability for carrier application; prototyping of carrier-specific subsystems before development when size permits; and paying specific attention to enhancing the connections among user, developer, and technologist. The results of this activity would benefit all carrier system evolution in the near-, mid- and long-term periods.

CARRIER-SYSTEM-RELATED RESEARCH AND DEVELOPMENT (R&D)

The following list highlights the research and development *that should be emphasized* to advance the carrier system and to make accessible some of the carrier system design options that are not available today. (The list is elaborated in Chapter 10, and the individual areas are discussed in detail in Volume II.) The time periods are indicated when achievement of significant

[2]It is estimated, for example, that the management activity described might cost on the order of $10 million per year, for a system in which the equipped ship and aircraft could cost over $8 billion. Savings attributed to the use of this management approach have not been calculated, but they could be large.

results can be expected, as are judgments as to the level of risk associated with the development of the technologies.

Risk is linked to the state of the art and of practice in the technology. Low-risk activities are those based on technology that has been implemented in the field at some point, requiring only the time and resources for application and integration in some current context. Medium-risk efforts are those for which the basic phenomena are reasonably well understood, and which may have been the subjects of successful laboratory experimentation, but which have yet to be applied to an operating system. High-risk endeavors are those for which the concepts and early theory and experimentation may exist, but for which much of the phenomenology remains to be described and implemented in hardware or software; the technical risk involved in trying to bring them to successful application is therefore high, because unknown or unexpected hurdles can prove highly expensive or even present insurmountable difficulties. Within the characteristic cost level of the systems and subsystems under consideration, higher risk entails higher research-to-hardware cost, although the performance of the hardware might reduce overall costs in the long run. Also, as will become apparent during the detailed discussion in Part Two, depending on the capability it can take more or less time to bring a capability to fruition, regardless of the level of risk.

1. Aircraft Systems

- Range extension with landing-speed reduction for CTOL aircraft (near to mid term; low risk).
- Structural materials suited to carrier environment, for low observability (LO) designs (near to mid term; medium risk).
- STOVL fighter/attack aircraft technology and prototype development (mid term; medium risk).
- Systems to facilitate and enhance night and bad-weather operations (near to mid term; low to medium risk)
- Lightweight counterstealth aircraft radar systems (mid term; high risk).
- High-performance rotorcraft concepts: ASW, tanker, carrier onboard delivery (COD), rescue (mid to long term; low to medium risk).
- Unmanned aircraft surveillance systems, especially HALE, with spacecraft reliability (i.e., long time on station, operating

without failures), air-to-air refuelable from the carrier, for AEW and other tasks (mid to long term; medium risk).

2. Passive Carrier Survivability (near to mid term)

- All areas of ship, aircraft, and weapon system signature management (low to medium risk).
- Damage isolation and control throughout the ship (low risk).
- "Instrumenting" the ship, to support damage control and maintenance (medium risk).
- Passive torpedo protection, including especially protection against underkeel torpedoes (could be low or high risk, depending on constraints and implementation).
- Advanced armor for selective protection of critical ship areas (medium risk).

3. Active Carrier Self-Defense

- Near-term missile and close-in weapons system (CIWS) gun system improvements (low risk).
- ATBM extension of AEGIS (mid term; medium risk).
- Near- to mid-term carrier active defense—air and torpedo (low to medium risk).
- Directed-energy and hypervelocity kinetic-energy weapons (long term; high risk), and low-yield nuclear warheads for special applications in air defense (mid term; medium risk).

4. Propulsion and Electrical Systems (mid to long term)

- Advanced, safe, high-power-density reactors (high risk); reactors with longer operating time between refuelings (medium risk).
- High-power-density, safe, energy conversion, conditioning, and management systems (medium risk).
- Electric drive (medium risk).
- All-electric "yellow gear"[3] (medium risk).

[3]Aircraft- and munitions-handling equipment.

5. Radio-Electronic and Acoustic Battle Management (Continues from present through long-term; carrier system needs modularity for continual upgrade.)

- Complete integration of the active carrier self-defense systems aboard the carrier, and with battle group defense and offense operations, including sturdy, multimedia, hard-to-detect communications (low to medium risk).
- LO and counter-LO sensors and sensor systems (medium to high risk).
- Advanced targeting systems, including "forward pass" with appropriate data link capacity and multimode battle integrity, for strike and defensive warfare (medium risk).
- Broadly defined EW and decoying systems to work with carrier signature management and defense (medium risk).
- Improved battle group command center designs, in association with carrier and battle group combat information system design (low risk).

6. Advanced Logistics and Manpower Engineering (near to mid term; all low risk)

- All areas affecting personnel and training; computer-based operation, maintenance, and support systems for the ship, aircraft, and weapons with emphasis on reliability, maintainability, and modularity for easy replacement of aging subsystems; rapid aircraft turnaround concepts; all applications of automation to these purposes and to ship operation and damage control—all these areas with the purpose of making the carrier system and its operations more effective and efficient with fewer people, and to "capturing" interior volume for other uses.
- Improving compatibility of carrier and underway replenishment ships.

7. Special Opportunities—opportunities are available to make special gains in understanding of carrier systems that, if capitalized on, can contribute invaluable data for mid- to long-term carrier design. Among the most interesting are the following:

- Use of the FORRESTAL, which is to be transferred to training status in 1992, as a test bed to experiment with and develop several of the concepts described in this report, for defense, logistic support, crew reduction, and operations (medium risk).
- Design and model studies of all aspects of large semisubmersible ships, with special attention to the technical problems, signature reduction, enhanced survivability, better cost estimates, and changed operational concepts in the long term (low risk).[4]
- Large-scale structural model experiments (possibly including a highly instrumented live fire test of a carrier destined to be sold for scrap), to help quantify better than is now possible the effects of underkeel torpedo explosions, to aid design studies of passive protection of carriers and other large ships (medium risk).

[4] Building a large prototype workable ship may, of course, become a high-risk endeavor.

PART TWO

OVERVIEW DISCUSSION

BACKGROUND

A study such as this cannot be started with a wholly clean slate. It is best to set the stage for understanding the scope of the study and the results it conveys by making explicit as many as possible of the underlying assumptions and premises. Even the definition of an aircraft carrier should not be taken for granted, since the results of the study will be based on a particular set of conceptions that may differ from others' understanding about aircraft carriers. This section lays out the main assumptions and premises that affect the scope and direction of the study, defines the carrier system as the study group understands it, and reviews the times when there will be significant opportunities to change the carrier system.

ASSUMPTIONS AND PREMISES

1. The study accepts that there will be U.S. naval forces, of which the carriers are a part, through the indefinite future. The future existence of aircraft carriers in some form is not an issue. However, carrier design and the way carriers carry out their missions could change significantly.

2. The number of carriers that should be in the fleet is also not an issue that this study will examine. But the study recognizes current realities. It is assumed that budgets will be tight in the foreseeable future, but that resources will be available to build and support needed maritime warfare forces.

3. No issues have been considered immune from examination. However, the fact that a question is raised, explored, and leads to some answers or system concepts does not necessarily imply that the answers are advocated as conclusions or recommendations of the study.

4. For purposes of this study, the nominal service lifetime of a carrier is taken to be 50 years, including overhauls, refueling of nuclear reactors, and modernization programs. While this assumed value might change in later circumstances, it seems reasonable in engineering terms and is in reasonable accord with current plans and programs for the carrier force.

(Current Navy planning factors call for an average carrier service life of 45 years, and changing force structure budgets will lead to earlier retirement for some of the non-nuclear carriers. However, the ENTERPRISE is just being refueled with another 20 years of service life in view, bringing its planned service life to 50 to 55 years. Rising costs of future major systems could easily lead to the addition of 5 years to planned service life for the other nuclear-powered aircraft carriers [CVNs] and their successors.)

5. The service life of a generation of aircraft is taken to be 30 years, with any individual aircraft remaining in service for 20 years. This is consistent with historic progressions of aircraft generations in both the sea- and land-based tactical aircraft forces, and it accounts for the fact that newer generations of aircraft, which are becoming more expensive than their predecessors and are taking longer to develop, will probably remain active over longer time intervals (with periodic upgrading) than has been the case heretofore.

6. It is assumed that large carriers—about the size of the NIMITZ class, or larger—will be nuclear powered. The nuclear vs. conventional power issue was argued thoroughly at the time of the CVV/CVN[1] discussions of the late 1970s. Nothing in recent experience suggests that non-nuclear power for a new generation of large ships of the aircraft carrier (CV) class should be preferred; indeed, future sustainability considerations would suggest using nuclear power for more ships if the initial costs are deemed supportable. Smaller carriers, some configurations of which are described, may be nuclear or non-nuclear, depending on views about the economics and other non-technical factors.

7. It is assumed that at least initially the strategic situation will continue to encompass generally friendly relationships with the nations with whom we are friendly now. However, the nature of those relationships, and the nature of relationships with current or potential opponents, may be such that the carrier force could interact in cooperative, guarded, or hostile ways with virtually any nation's military forces at some time in the future. There is a further implication that C^3I equipment and strategies will have to be designed for ready compatibility with those of new allies, and to have their use denied to new enemies, perhaps on short notice. Therefore, the

[1]CVV (aircraft carrier [medium]) vs. CVN (aircraft carrier [nuclear]).

operational context defining the military capabilities needed in a future carrier requires attention to potentially opposing capabilities rather than intentions of any potential opponent. That is, there is no "threat" national force per se, but there will be extensive and varied potentially opposing military capability with which the carrier force may have to contend over the lifetime of the ships.

THE AIRCRAFT CARRIER SYSTEM

The carrier is a major tactical air base fitted into a horizontal, floating, mobile package roughly as long as the Empire State Building is high. It provides:

- A specialized form of runway (in effect, parallel runways) capable of simultaneous aircraft launching and recovery or rapidly alternating launches from and landings at several points on the "runway";
- Tie-down and hangar space for the aircraft;
- Aircraft refueling, maintenance, repair, and subsystem setup and calibration space and facilities;
- Weapon storage, loading, and setup space and facilities;
- Aircrew and aircraft service crew living, planning, health, and recreational space and facilities; and
- Living space and health and recreation facilities for the crews that operate the ship, the air wing, and their facilities.

The carrier provides for the ship's self-protection in case of war, including shipboard weapon systems in addition to defensive aircraft, and targeting for those systems; and control and repair of damage in case the ship is hit in war or damaged by a peacetime accident, so that it can keep operating.

The carrier is part of a maritime warfare and naval aviation system. In addition to the carrier, the system includes:

- Sea-based aircraft for strike warfare and for antiair, antisurface-ship, and antisubmarine warfare;
- Surveiliance, command, control, communications, intelligence (C^3I), and targeting systems, and other combat support such as electronic warfare and midair refueling, to enable them to carry out offensive warfare;

- The weapons they use;
- Offboard systems, on other ships or land based, to help protect the carrier and the battle group, in addition to the defensive systems aboard the carrier;
- The C^3I and targeting system necessary for the total defensive task; and
- Facilities and work space, aboard the carrier or one of the ships that accompanies it in the battle group, for the battle group or battle force commander, his staff, and operating crews, including command, control, and communications with links up and down the chain to other elements of the carrier battle force, to other fighting forces, and to regional commanders-in-chief (CINCs) and sometimes to National Command Authorities (NCAs).

Viewed in broad perspective, the system components may be part of the aviation complement of the carrier; they may be part of the carrier itself; they may be part of the fleet that accompanies the carrier; or they may be land- or space-based, even though they are part of (i.e., "organic" to) the seaborne aviation system. The entire system operates under the command of a battle group or battle force[2] commander, who is in turn under the command of a regional CINC.

Like any major system, all the components of the carrier system are tied together in complex feedback loops. **Significant changes in one part of the system must affect the distribution of functions and costs in the others.** Although this study is focused on the technology and design of the carrier of the future, that design can be affected profoundly by changes in the concepts of operation and/or the design of any of the non-carrier components of the system as well as in the aviation, the carrier, and their subsystems. Also, constraints and opportunities in carrier design can and will affect the design and operation of all other parts of the system. Thus some of the issues that will drive the carrier design must be resolved in other parts of the total system as well as in the design of the carrier.

[2] A battle force includes more than one carrier and elements of more than one battle group.

INITIAL CONDITIONS OF THE STUDY

The Carrier Air Wing

The shape, size, and functioning of the carrier depend strongly on the aircraft that operate from it. The aircraft characteristics determine the landing space and catapult (or other takeoff) requirements of the carrier deck, and for a given hull form those requirements essentially determine the design the ship. However, the carriers available at the time aircraft types are replaced likewise influence the design of the aircraft. The current large-deck carriers and their carrier air wings are thus matched to each other within the carrier system, as the result of decades of evolution of both.

The carrier air wing currently includes between 80 and 100 fixed-wing and rotary-wing aircraft, with the former constituting the vast majority. The fixed-wing aircraft complement is composed entirely of conventional takeoff and landing (CTOL) aircraft, with the exception of the Marine Corps' AV-8B vertical or short takeoff and landing (V/STOL) light attack bomber that might be carried during some missions. The Navy combat aircraft currently include the F-14 long-range fighter, the F/A-18 fighter and light attack bomber (whose mission spectrum concentrates mainly on attack), and the A-6 medium attack bomber. Fixed-wing support aircraft include EA-6B aircraft for electronic warfare (EW) and aircraft for midair refueling, both built on the A-6 airframe; antisubmarine warfare (ASW) aircraft, using the S-3 airframe; and the E-2C airborne early warning (AEW) aircraft that help manage the defense of the carrier and the maneuver of aircraft forces in strike warfare. Aerial resupply and personnel exchanges are performed by carrier onboard delivery (COD) versions of the E-2 and the S-3. Helicopters include variants of the H-60 for ASW and air-sea rescue, and of the CH-53 for heavy lift.

The aircraft currently in the carrier air wing will be of obsolescent technology and will reach the end of their planned service lives during the early 2000s. Replacement plans are currently either under way or under study and discussion in the Navy, depending on the aircraft, and they have entered the Office of the Secretary of Defense (OSD) and congressional budget processes.

The A-12 medium attack aircraft that was in development was canceled in early 1991 for technical and management reasons. Its airframe had also been under consideration for adaptation to fulfill some or all of the other roles currently filled by the A-6, and possibly others are noted. As this is written, a new aircraft or concept for the A-12 mission has not been

announced. However, such a successor will be needed at some point since the A-6 is one of the older aircraft in the fleet. In consideration of potential military opposition to the new aircraft, the A-12's planned characteristics of range, payload, and low observability will have to be accounted for to some degree in any succeeding design. Such an aircraft, labelled the A-X, will be considered here to be a part of the carrier air wing beginning shortly after the turn of the century. Essentially the same characteristics of compatibility with the NIMITZ-class carrier can be assumed for the A-X as were planned for the A-12.

The long-range air defense role had been planned over the long term to be fulfilled by a progression from the F-14 to the Navy version of the Advanced Tactical Fighter (NATF), which has been deleted from the Navy budget (at least for the time being). Improvements to or redevelopments of the F/A-18 have been under study for the light fighter and attack roles, and a stretch version (F/A-18 E/F) to increase its range may fulfill the long-range fighter role.

The Navy has had an Advanced Tactical Support (ATS) aircraft under study to fulfill the ASW, AEW, EW, and other surveillance roles currently carried out by the S-3, E-2C, and EA-6B. This may be a single new airframe, some combination of the A-X and modernized S-3 airframes adapted to the new missions, or some other combination of aircraft designs not yet selected. The logistic support role will also have to be provided for after the E-2 and S-3 airframes reach the end of service life.

All of these new aircraft are CTOL aircraft. The Navy has considered the possibility of a short-takeoff, vertical-landing (STOVL) aircraft for some of the combat aircraft roles in the more distant future. This, together with rotary-wing aircraft and possible future hybrid fixed-rotary-wing designs, opens the possibility of a succeeding generation of "powered lift" aircraft—an aircraft type that has been under consideration regularly since World War II, but that is now in the operating inventory only in the AV-8B and the helicopters.

Current Status of the Carrier Fleet

The diagram presented in Figure 1.1 shows the time lines from date of commissioning to decommissioning (including the end of the assumed, nominal CVN 50-year service life) for the carriers currently in the fleet, under construction, and authorized by Congress. Although the Navy has included long-lead item funding for CVN-76 in the FY 1993 budget, this has

not yet been authorized by Congress. Approximate time lines for the new generation of aircraft are also shown, to highlight the relationships between the carrier and aircraft lifetimes. The following key points should be noted from the relationships illustrated in Figure 1.1.

Six conventional carriers are scheduled for retirement or conversion to training status before the year 2000 as new NIMITZ-class carriers are commissioned, with the carrier fleet limited to 12. The remaining KITTY HAWK(*) classes of carrier, and the ENTERPRISE (the first CVN), will be about 50 years old in the period from 2010 (KITTY HAWK) to 2018 (JOHN F. KENNEDY). The NIMITZ and carriers in the NIMITZ class will need to be replaced starting in 2025. Planned refueling of the ENTERPRISE will keep it in the fleet until 2011 (or possibly longer).

Viewed alternately, if there is a 12-carrier active fleet, between about 2000 and 2025 the carrier fleet will have 8 NIMITZ-class carriers and it will need 4 replacements for the older conventional classes and the ENTERPRISE. Thus, during the three time periods being considered as relevant to the evolution of carrier technology, the opportunities to incorporate the technology in new designs can occur as follows: near term, involving the CVN-76; mid term, about 2005 to 2020, during which 3 new ships will be needed, and post-2025, when the NIMITZ class will start to need replacement. At any point after 2010, more than 3 new carriers may be needed if the number in the active fleet again exceeds 12 carriers. Much of the new technology can be incorporated in the existing carriers during retrofit and modernization programs, during any of the periods when elements of the technology become available, independently of carrier replacement needs or decisions.

The new generation of aircraft that will probably come into the fleet during the period 2000 to 2010 will overlap the near-term and early mid-term carrier replacement time periods (i.e., these aircraft will move from existing to new carriers while in service). But that generation of aircraft will start to need replacement after 2030, during the long-term carrier replacement period. Since the current and the next generations of carriers will each have to accommodate two generations of aircraft, the evolution of the ships and the aircraft, together, must be considered in thinking about the carrier itself.

Thus, whatever the Navy decides about the directions of evolution in the carrier force, it is necessary to contemplate a roughly 45-year (~2003 to 2048) evolution of the aircraft-plus-carrier system before wholly new systems will have replaced every vestige of the current-design systems in service. It is also possible that the carrier-plus-aircraft system that replaces

the last of the currently authorized NIMITZ-class carriers may well be in operation virtually up to the end of the 21st century.

OPERATING ENVIRONMENT AND CONTEXT

To meet the terms of reference of this study it was deemed essential to examine the operational and military environment in which the new ships will likely operate. This environment will determine the requirements for the future generations of aircraft and for defense of the carrier. Without an understanding of such requirements, the design of future carriers would have no sound operational foundation.

GENERAL WORLD SITUATION IN 1991

The fall of 1989 saw a major change in the world strategic situation, with the turning inward of the USSR, the freeing of Eastern Europe, and the public perception in the Western alliances that the Soviet threat had evaporated. This was but one set of dramatic events in a longer-term continuum of trends toward a differently oriented world geopolitical scene, requiring a differently oriented U.S. strategic posture. Moreover, in part because of the events noted, it appears that for the indefinite future U.S. strategic posture will have to be revised in an environment of constrained defense budgets.

The long-term trends have included the growth of two major economic groupings—an economically unifying Western Europe, and a group of Pacific Rim countries with economies being integrated by Japan—whose GNPs are each of the same order as that of the United States and whose populations are larger. These economic groupings, militarily allied with the United States to meet Soviet militancy when it existed but increasingly our economic competitors, have technological capability that equals or is superior to ours in various parts of the commercial sphere and is catching up in the military sphere. They have or can build strong military forces. It appears safe to project that over the lifetimes of the next generations of carriers other powers will grow important, new power blocs will appear, and U.S. relations with various nations will change.

In the Third World,[1] which is subject to severe development pressures and where there are resources vital to the well-being of the United States and its allies, there has been an increase of nationalism and political instability exacerbated by the heightening of ancient rivalries and conflicts in many areas. These trends have been accompanied by the growth, aided by prior and current arms sale policies of the USSR, the United States, and our allies, of military strengths that make conflicts among those nations particularly destructive and dangerous, and that can be highly threatening to U.S. military forces should we have to use those forces in defense of our interests and those of our allies. The portent for the industrialized and developing nations and their economic well-being embodied in the conflict with Iraq has heightened our appreciation of the nature of the Third World military challenge. The outcome of Operation Desert Storm may deter many potential threats against U.S. and allied interests from the Third World, at least in the near term, but the antecedents of that conflict also illustrated that such challenges can arise unexpectedly and quickly.

In the future, Third World military capabilities are likely to continue to improve, as a result of economic competition among the industrialized countries for arms sales, the political imperatives of arming allies in diverse areas, and because indigenous technological capabilities of growing regional powers, such as China, India, and Brazil, are also increasing and being spread. Third-World-oriented arms control proposals being considered now will take a long time to implement if they are agreed upon, and they are more likely simply to slow rather than to stop the drift of advanced arms into Third World arsenals. Although many Third World countries may not yet be adept in the development and use of advanced military systems, several may be expected to become so over the lifetimes of the ships being considered here.

The world's economic trends have led to internationalization of the world's economies, so that the United States depends heavily on overseas sources of resources and manufactured goods as well as overseas sales of our own products. The sea and air lines of communication to those sources are thus vital to our strength and welfare, as well as to our defense. At the same time, our freedom to use bases in allied countries to protect U.S.

[1] "Third World" is used here as the conventional shorthand for nations other than the combination of NATO, OECD, Japan, and the Soviet Union. The countries of Eastern Europe are included for convenience with the countries other than the Third World; they are mainly land-locked, with little easy access to open oceans.

interests beyond direct defense of the allies has been reduced. Our allies wish to have a say in how we use the bases on their territory, and they have at times objected to our using them for purposes they disagree with or that they fear may work against their own interests. Such patterns can be expected to become the norm in U.S. overseas military involvements.

As specific elements of our overseas posture become more uncertain or insecure, the Navy must come to represent an increasingly important part of our forward security posture. It provides the only force that can establish a visible, persistent presence in a troubled or threatened area for stabilization and deterrence without impinging on the sovereignty of any nation in such an area, and for rapid response to an attack on our interests with military force. But while one cannot say whose forces, specifically, the new carrier system should be designed to fight over the next 20 to 50 years, some categorization by potentially opposing capabilities is possible.

TRENDS IN MARITIME WARFARE[2]

Worldwide, broad-area surveillance by many nations, including our own, will mean that unless ship signatures are reduced it will become increasingly difficult for naval surface forces to hide in the vastness of the ocean. To avoid telegraphing moves, unless that is desired, to engage opposition on land at the sometimes large geographic distances that can be involved in Third World contingencies, and to make targeting and attacks against the battle force more difficult, dispersed battle force formations and strike warfare beginning initially at some distance from target areas are visualized for the early stages of warfare involving carrier forces. This would continue a post-World War II trend toward dispersal of the battle group, with offensive tactical aircraft or missile firepower concentrated from increasing ranges. However, the evolution of threat weapon systems will affect this trend in complex ways that are explored in some detail at various points in the remainder of this report.

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[2]The trends noted in this section and the technology involved are described in detail in *NAVY-21: Implications of Advancing Technology for Naval Operations in the Twenty-First Century*, a report of the National Research Council's Naval Studies Board (National Academy Press, Washington D.C., 1988).

Briefly, defense of the fleet during the period of severe Soviet threat came to encompass three interlocking defense zones: interception of airborne attackers by aircraft at long range, area SAM intercept of aircraft or missiles leaking through the outer air defenses in an intermediate-range zone, and close-in ship self-defense against attacking missiles and torpedoes. The range of the threat, of the strike systems, and of the defensive systems has continued to increase, as has dispersal of fleet units. At the same time, stealthy opponents—aircraft, submarines, and their weapons—that attack a battle group tend to shrink the battle space of individual ships. This will require enhanced ship self-defense capability. It could cause the ships of a battle group to draw together for more mutual support in defensive warfare.

Systems for strike warfare can now take several forms, and these will be further improved in the future. They include:

- Close-in attack of targets by aircraft using free-fall or guided weapons;
- Attacks by aircraft standing off from the close-in point defenses and launching guided standoff weapons;
- Attacks by air-, surface-, or subsurface-launched long-range missiles against targets located in advance by space-based or aircraft surveillance systems (pretargeted mode), or with real-time assistance by forward surveillance aircraft that pass final target information to the missiles after they have reached an appropriate point in their flight paths ("forward pass" mode).

As a general matter, systems using guided weapons in all categories will destroy targets with greater economy of force (i.e., earlier completion of military tasks using fewer aircraft sorties and with fewer aircraft losses) than those using unguided weapons. The longer-range weapons tend to be larger and more expensive than the close-in weapons, and therefore fewer in number. A carrier magazine carries about an order of magnitude more air-to-surface weapons deliverable at long-range (by direct or standoff aircraft attack) than can be included in the form of long-range surface-to-surface missiles even in advanced designs of surface combatants. However, in high-threat situations it could be undesirable to bring the carrier close to hostile shores before countercarrier weapon systems and forces are reduced or eliminated. It was indicated in *NAVY-21* (National Academy Press, Washington, D.C., 1988) that the most efficient and effective approach to battle group strike warfare in such situations will be to reduce the threats to the carrier and its aviation with surface- or submarine-launched long-

range missiles that are targeted by means ranging from carrier aircraft to external assets such as those in space, depending on the type of target. Sustained strike warfare by carrier aviation would follow this preparation stage. (In some situations not demanding extensive and sustained attacks, the initial strike may be enough to settle the military issue.)

Both offensive and defensive maritime warfare doctrines and systems will greatly increase the importance of the "information war" for targeting sea-based strikes and to alert individual ships to approaching attackers and weapons and to help in their ship's defense. The information war is a contest in which each side attempts to learn as much as possible about the compositions, locations, and activities of the other, and about third parties in the vicinity of a conflict, while denying such information about itself. Information denial will involve broad application of stealth technology, signature management, electronic support and countermeasures, and concealment and deception (C&D). Information gathering, and many other information-related activities such as communication and navigation, will depend on systems in space, without which the Navy will be unable to operate, as well as on airborne systems. The information war and its concomitant radio-electronic and acoustic battle management (REABM) are coming to involve diverse, expensive, technically complex system designs for all the above purposes.

Although weapon range initially ran ahead of over-the-horizon targeting of moving targets in U.S. systems, the information systems, including sensors, communications, and processing and rapid integration of information from many sources, are gradually facilitating targeting for the standoff weapons. Targeting against fixed targets has not been a problem per se, although extensive information must often be collected to facilitate weapon guidance by such schemes as digital scene matching. Use of Global Positioning System (GPS) coordinates for targeting and weapon guidance will make guidance less expensive and more flexible. However, this implies routine mapping of target coordinates in the GPS grid, which is not a current practice.

In all the key areas the United States Navy is ahead of potential opponents. However, maintaining the lead has not come cheaply; we have been strongly challenged by the Soviet Union, and many of the important capabilities applicable to maritime warfare have gradually been spreading to other countries.

FUTURE MILITARY ENVIRONMENT

The Soviet Union

Although the USSR has reduced its threatening demeanor, we cannot be certain that the current trends will continue. The Soviet Union has embarked on an ambitious program to restructure its economic and political system, but the prospects for success remain clouded. Whether the effort fails or succeeds, there remains the possibility of renewed militancy and hostility to the West, possibly emerging from internal political upheaval. Even if the Soviet Union is fragmented, some elements of the country will retain much of the current military capability, and the use of a real or imagined external enemy by leaders seeking a cause for national unity has not been unheard of in recent history.

Although the USSR has been reducing some of its military forces as the Warsaw Pact has dissolved and in accord with the conventional forces Europe (CFE) and coming strategic arms talks (START) agreements, they retain high maritime warfare capability that they continue to improve. This includes the attack submarine force and long-range, land-based naval aviation, both of which represent highly stressing capabilities against the U.S. fleet. Among the ongoing improvements is the beginning of a new class of large aircraft carriers; the Kuznetsov (formerly the Tbilisi), which fields first-line tactical fighter and attack aircraft, is the first carrier of the class. A long-range bomber fleet, long-range air- and surface-launched missiles, quieter attack submarines, submarine-launched missiles, and wake-homing, underkeel exploding torpedoes with large enough warheads to totally disable or sink a NIMITZ-class carrier all exist, and many of these force elements continue to be improved.

Thus, although in the future we could anticipate longer strategic warning of a land war if there were to be a resurgence of Soviet hostility, the tactical warning situation for the Navy would remain much as it is today. The Navy must remain prepared to meet Soviet naval warfare capability that has not been changed by the Soviet withdrawal from Europe, if that should later become necessary.

Relevant Third-World Military Capabilities

Third World countries are rapidly acquiring military capabilities that can seriously threaten our naval forces and that can effectively oppose strike warfare by naval aviation over land. These capabilities include:

- A great proliferation of antiship cruise missiles, which can be expected to incorporate stealth characteristics and terminal avoidance maneuvers as missile generations progress, and which can be air-, surface-, or submarine-launched;
- Accurate (e.g., 100-m or less circular error probable [CEP]) long-range ballistic missiles with conventional unitary or distributed-effect, chemical, and possibly biological warheads and, at some future time, nuclear warheads;[3]
- Advanced tactical aircraft;
- Quiet, modern diesel and closed-cycle submarines, with the possibility that one or more nations may acquire nuclear-powered attack submarines;
- Mines and advanced torpedoes; and
- Effective air defense weapons.

Table 5.1, repeated from the synopsis, Chapter 2, and based on unclassified sources, shows some of these Third World weapon system holdings and the countries where the capabilities originate.

Ballistic missiles, while they are clearly threatening in land warfare against fixed targets, may not appear as threatening against highly mobile targets like aircraft carriers. This is true as long as the missiles are limited to delivering ballistic, unitary high-explosive warheads, since targeting would be difficult and a ship at 30 knots could move 5 nmi in the 10-min flight time of a missile. Thus, such missiles are not now a threat to the Navy. But they can become so.

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[3]Distributed-effect warheads are those with submunition payloads that are distributed in a pattern designed to include and damage the target. The probability of a hit is increased thereby, and although each submunition inflicts less damage than does a large unitary warhead, the effect of several hits distributed over the target could in some circumstances be more damaging than the effect of a unitary warhead.

TABLE 5.1 Overview of Third World Military Capabilities, Current-2010

CAPABILITY	MAIN COUNTRIES HAVING	MAIN COUNTRIES PROVIDING
Modern tactical aircraft in significant numbers (stealth technology in demand and appearing to some extent in designs)	All in Middle East and Southwest Asia; India; Pakistan; China, Latin America; Japan; North and South Korea	U.S.; USSR; France; U.K.; some indigenous
Anti-ship guided missiles; potentially stealthy; fast maneuvering	70 countries	France; U.S.; USSR; China; others
Modern, quiet non-nuclear submarines (44 now; 84 near term)	India; Pakistan; Egypt; Israel; South Africa; Taiwan; China; 7 Latin America; South Korea; Middle East; Southwest Asia: Southeast Asia; others considering	Germany; U.K.; France; Sweden; the Netherlands
Mines & advanced torpedoes	All that have submarines; 21 countries with naval mining capabilities, some modern	Same as above, plus USSR, U.S., others
Chemical weapons	14 countries have capability; 10 more developing it	Germany; Brazil; basic chemicals easily available

Ballistic surface-to-surface missile (SSM), range >200 mi; potentially, maneuvering warheads	China; Brazil; Israel; Libya; Egypt; Saudi Arabia; Iraq; Iran; India; Pakistan; North and South Korea	China; Brazil; USSR; North Korea; others; some indigenous
Nuclear weapons	Tested weapon/device: China, India; Assumed: Israel, Pakistan, South Africa; possible soon: North Korea, Brazil, Argentina, others	Related help attributed to China, Germany, Brazil (West is not vigorous in controlling relevant technology)
Laser weapons vs. sensors & people	Any can build laser for blinding; range finders common	General technology flow; USSR & NATO countries working on systems
Modern C^3I & targeting, including space-surveillance capability	All have communications systems; Japan, China, India, Israel have satellite launch capability	USSR, France selling ≤ 10-M-resolution space data
Modern ground forces (tanks, artillery, helicopters)	All Middle East and Southwest Asia; China; Pakistan; India; South Africa; North and South Korea	U.S.; U.K; France; USSR; Italy; Germany
Modern air defense weapons/systems (especially shoulder-fired)	All Middle East and Southwest Asia; India; Pakistan; Japan; China; North and South Korea; many others	U.S.; USSR; France; U.K.

NOTE: Figures include Iraq, which, although now destroyed, can be expected to rebuild by 2010, with help from outside.
SOURCE: Summarized from unclassified data published by ACDA, Jane's, IISS, and USN.

If a ship's position could be ascertained accurately at the time of launch, and if there were barrage fire by many missiles, then chemical warheads could possibly deliver a damaging attack. A salvo of a few nuclear warheads could have a reasonable chance of detonating one within killing distance of a ship. Biological warheads would do no immediate damage, but they could impair a carrier's operations in a matter of days. Distributed-effect warheads having many small, energetic submunitions that could seriously damage or even penetrate the flight deck, the superstructure, and exposed aircraft could be launched in such a salvo with a good chance to damage the carrier and its air wing. For a nation seriously threatened by carrier aviation a massive launch of a large part of its ballistic missile inventory might be a small price to pay for the political victory of damaging or achieving a mission kill against a carrier.

In the more distant future, but within the lifetime of a generation of carriers that may be acquired during the period 2000 to 2020, maneuvering warheads for ballistic missiles could be developed and fielded, either by advanced countries that would also pass the technology to the Third World, or by advancing Third World countries that would pass it to other countries in addition to incorporating the technology into their own systems. With appropriate guidance, large, conventional unitary or distributed-effect ballistic missile warheads could then attack even a moving ship.

Finding, tracking, and targeting a ship would remain a difficult problem, but not impossible as time progresses. The Argentine air force was able to target British ships during the 1982 conflict in the South Atlantic, including ships not very close to the islands. Most developing nations are building advanced civilian communication systems that can be turned to military use in time of war. Many surveillance satellite systems have been launched in the interest of resource and weather surveys. The United States, France, and the USSR have already offered data from such satellites for sale; the resolution of the data is sufficient to detect naval targets. As time passes we can expect increasing Third World ability to launch surveillance and communication satellites. Depending on the political issues involved in any potential conflict, advanced countries may be willing to pass surveillance data to potential belligerents.

Submarines, commercial ships, and aircraft operating within the accurate navigation that will be available via the U.S. GPS and the Soviet GLONASS systems could determine ship locations accurately enough to launch attacks into a lock-on-after-launch "basket." Reducing response time and location of targets within less than a mile, especially with the help of surveillance aircraft, ships, and submarines in a pre-hostilities environment, will not be

insoluble problems for determined military forces. **It must therefore be assumed that the tactical problem of maintaining surveillance, or finding a carrier and targeting it, will be solved in the long run by several regional powers.** (The effect of signature management on this capability will be discussed in a later section.)

The weapon systems available for attacking a carrier would then include any of the systems listed above. Although the large, wake-homing, underkeel torpedoes are not yet available in the Third World, they could become available during the lifetimes of the carriers being considered here. Other types of homing could be associated with underkeel torpedo attack.

The only major kind of system that the Third World may not have at its early disposal is an analog to the Soviet BACKFIRE system delivering long-range, supersonic missiles. Developing bomber-class aircraft is difficult and expensive, and such aircraft may not appear in the Third World. However, modern transport aircraft can be adapted to launch missiles, including heavy, fast, long-range ones, so that in time a non-Soviet long-range air threat to the fleet could appear. Because of the nature of the aircraft, it may not be as stressing for the outer air battle as the Soviet air threat has been, but denial of continuous combat air patrol (CAP) deep over hostile territory where the transports may be orbiting, prior to establishment of friendly air supremacy, could contribute to surprise in such launches.

Military capability that the carrier system can expect to face in strike warfare during its lifetime includes sophisticated land-based air defenses. The air defense capabilities include Soviet, U.S., French, and British systems, some of which have high performance and are very resistant to countermeasures. In some countries these defenses are tied together in defense networks including early warning and cooperative combat among dispersed defense sites. The United States encountered such capability, based on much cruder systems, in Vietnam, and the performance of such systems has improved greatly since then. As time progresses, we can also expect to see some forms of laser weapons dispersed throughout the world. Such weapons may not, in the early years, have sufficient power levels to damage an aircraft or a missile airframe but they can, even now, blind sensors and aircrews.

All these capabilities will place a premium on carrier aviation attack using low-signature systems; attack from standoff; radio-electronic battle management of the information aspects of the air (as well as naval) warfare, including effective command, control, and communications with integrated electronic warfare and force-wide signature management support; and efficient and effective targeting systems and weapons that can destroy targets

without requiring many repetitive sorties and accompanying aircraft losses. Such capabilities were demonstrated during Operation Desert Storm, and they clearly contributed to effective air operations in that war.

Finally, it should be noted that several Third World countries have developed extensive skills and implementing organizations in terrorism and sabotage. These pose a danger to a carrier mainly when it is in port and in restricted or crowded waters where small boats, airplanes, and trained swimmers can pose a hazard to the ship and its crew. Although advanced onboard monitoring and communication technology can help in meeting this threat, the main counter will lie in awareness and security precautions together with physical protection using conventional and improved defense systems that are well within current capability.

Allied Countries

Despite the recent marked changes in the world situation, the United States and its major allies in Europe and the Far East have made no move in the direction of dissolving the alliances; indeed, they have articulated reasons not to do so. However, the subsidence of the Soviet threat together with the heightening of economic competition among the allies must inevitably change the nature of the alliances. Factors in the economic competition are likely to come to the fore. An economically united Western Europe, Japan, and the Republic of Korea (possibly reunited at some point with its Korean neighbor to the North) can all be expected to advance their technological capabilities. While the orientation may be commercial, the technologies of greatest importance, in the electronic, computing, and materials areas, will have dual uses, so that military capability among the allies will grow.

This capability is already very strong. In time, especially if there is a tendency to slow U.S. defense R&D for advanced systems, it can be expected that U.S. and allied military capabilities will approach essentially the same level. The United States will have to guard that our level of military capability does not fall below that of our allies. We will have to hold our own and even continue to surpass our allies in military capability if we are to continue in our traditional leadership role. This applies especially to the naval and maritime warfare area, where the protection of freedom of the seas and the ability to project power ashore from the sea are of vital importance to all and where we have had the preponderance of highly capable naval strength for the task. A diminished U.S. naval power could

lead to the adverse effect of enhancing any divergence of interests and actions that the economic competition might bring about.

OVERALL SIGNIFICANCE OF THE DIFFUSE THREAT

Political change can happen much more rapidly than the carrier system can be changed in any significant way. It is thus fruitless, and could be seriously misleading to the public and defense planners, to try to predict which nations any carrier system built to operate during much of the 21st century will have to fight over its lifetime. Rather, the carrier system will have to be prepared to work with and contend with a flexible array of capabilities in what is becoming an increasingly unstable and transient set of world political and economic relationships.

All the indications from the above sketch of the current world situation and geopolitical, technological, and military trends are that the naval aviation system will have to continue to strive for the best technological capability that can be achieved. Despite the relaxation of tensions with the Soviet Union, nothing in the trends presages a relaxation of the need to be able to meet and overcome advanced military technological capability in any areas of the world where U.S. interests may be threatened in the future.

Some may argue that the Operation Desert Storm experience in rapidly overcoming resistance by a well-armed enemy suggests that the above conclusion is overstated. There are two responses to this argument. The first is the historical observation, repeated several times during the past century and a quarter (e.g., in Japan, the USSR, Korea), that over time forces newly equipped with modern systems will become adept at developing and using them. The second is that the use of the most advanced U.S. equipment to overcome resistance rapidly saved many casualties and avoided potentially severe national political divisions, bearing out the value and indeed the necessity of keeping the technological edge. A very substantial technical lead may become essential in fast-moving technical areas.

Although the *need* for advanced technological capability in the Navy and the Marine Corps will not diminish, the *nature* of the capability could change significantly. The shift in threat priorities and possible combat areas will mean a reduced likelihood of open-ocean fleet combat at long range. An increase in operations in coast-oriented or littoral areas can be anticipated. There, the fleet will become more accessible to proliferated, shorter-range opposing tactical aviation and to land- and submarine-launched antiship weapon systems. The long-range outer air battle and the

missile-based area defense zones would then tend to merge. The battle for air supremacy will move away from the three-tiered open ocean battle that characterized planning to meet the earlier Soviet threat, to become a mixed battle involving integrated use of antiaircraft missiles and fighter aircraft. **Incorporation of stealth in threat systems, the underkeel torpedo threat, the continuing threat from naval mines, and a growing ballistic missile threat will require more emphasis on self-defense of the carrier.**

Although other geographic areas will be emphasized in U.S. planning now, we must also be ready to respond in case there is a resurgence of Soviet hostility, which could occur virtually overnight. In that event, and for some Third World situations (such as the anticipated continuing U.S. presence in the Persian Gulf) requiring operations at very long distances from the carriers, the Navy will continue to need long-range aviation such as it has and is planning now.

Over time, both threats and naval aviation characteristics will change. The range and payload of tactical attack systems on both sides will increase, as will the ability of U.S. antiair warfare (AAW) systems to engage stealthy threats. Low observability may enable Navy attack aviation and strike warfare systems to operate with less need for fighter cover, while increased stealth on the part of attacking systems will require more close-in defense of the battle group and the carrier. Defense at long range could come to depend on any of several alternatives. The latter might include "forward pass" missiles that can be launched by fighter aircraft, attack aircraft, or ships and submarines, with terminal targeting by tactical combat or advanced surveillance aircraft in the target area. Any of these possibilities can affect the form and composition of the carrier air wing, carrier self-defense, and the distribution of battle group AAW and ASW defense in successive generations of systems. The ships must be designed with flexibility to accept the variations as the need for them arises.

6

CARRIER SYSTEM TECHNOLOGY

One cannot talk about future carrier system technology without dealing with the design and operational issues the technology poses, and one cannot talk about the issues without having had some exposure to the technology. In keeping with the terms of reference of the study, this *Overview* summarizes the technology, but to be concise and to adhere to the main point of the study it must concentrate on elucidating the issues that the technology, in combination with the changing operational context, raises with respect to future carrier system design.

The key areas of technological advance that will affect the carrier system over the next few decades are summarized below in Tables 6.1 through 6.7. The advances and their significance are elaborated, and they are discussed in Volume II. No attempt has been made to be complete, since all of the relevant areas and varieties of technological advance and all their ramifications are too numerous to mention in a brief survey. However, the advances listed are believed to bear, at least potentially, the greatest significance for carrier design in the future. Many possibilities are mentioned and described that may in the end be proven undesirable for incorporation in carrier system design. Indeed, some of the advances may have influences that conflict with each other. Mention of a technology therefore implies neither acceptance nor rejection. The purpose of Tables 6.1 through 6.7 is simply to convey information. Costs are not included here; important cost factors are treated in later discussion.

The presentation in these tables concentrates on the possible technological advances that could have a significant impact on carrier system design and operations. The critical concerns raised by both operating environment and technology trends are discussed in the subsequent sections.

Although the carrier is the primary concern of this study, the carrier's aircraft and their weapons are the reason for having a carrier, and for that reason they are presented first.

TABLE 6.1 Key Advances in Carrier Combat Aviation Technology

DESIGN TRENDS AND POSSIBILITIES	SIGNIFICANCE	WHEN*
Stealth	Easier penetration of defenses; simplified EW support; internal carriage of weapons, possibly smaller weapons load (depending on size); changed shapes, sizes, maintenance, and operating procedures	90s
Increasing thrust-to-weight ratios and engine efficiency	Supersonic cruise; increased range and payload, leading to larger, heavier CTOL aircraft; powered lift fighter aircraft increasingly competitive	90s to mid term
Advanced, all-digital avionics	WHAT: Electronically scanned steerable array broadband radars; IRST; high-capacity computers; multisensor integration, noncooperative IFF, for air-air; simplified, multifunction, high-resolution displays; automatic target recognition, automatic bombing systems linked to GPS for close-in and modest standoff attack**; LPI/LPD communications; higher reliability for all due to VLSI all-digital technology SIGNIFICANCE: Cooperative air-air engagement, including forward pass, "zero-CEP" ground target attack from standoff, or within close-in defense reaction time line; in all cases, greater economy of force; earlier and more target kills with fewer sorties and fewer friendly losses; reduced maintenance coming from higher reliability	All currently in work; will become available over mid-90s to mid term

STOVL fighter/light attack aircraft	**WHAT:** F/A-18 class, single-engine to preserve minimal (~5%) weight penalty over equivalent carrier-qualified CTOL†; supersonic cruise; incorporates stealth characteristics **SIGNIFICANCE:** Forward defense and attack operations possible off small carrier (e.g., LHA-size) w/o catapult/arresting gear	Mid term, if start not later than mid '90.
STOL characteristics for CTOL via vectored thrust	Reduce landing distance by ~30%; fit larger aircraft within current deck, catapult, and arresting gear capacities; more responsiveness for "bolters" missing arresting wires because engine @ full throttle during landing, thrust adjusted with reverser vanes††	1st decade; need current/next-generation aircraft carrier design changes

- * Times are general, only: "90s"; near term (1993 to 2005); mid term (2005 to 2020); long term (post 2020)(see Figure 1.1).
- ** Detailed prior mapping of potential target areas in GPS coordinates needed for all attack missions using standoff.
- † Twin-engine design would carry unacceptable 20% weight penalty, due to cross-connections for one-engine-out landing and T.O., unless standards waived.
- †† Penalties: ~10% added weight for vectored thrust and possibly added pitch control surfaces; need to provide pilot display of landing scene on HUD (or equivalent) or design in other means for over-nose visibility at high angle of attack. Note: STOL characteristics can also be provided via high-lift wing designs, with similar weight penalties for more extreme measures like boundary layer control.

TABLE 6.2 Key Advances in Combat Support Aviation Technology

AREA AND KIND OF ADVANCE	SIGNIFICANCE	WHEN
SENSING: As for combat aircraft avionics, extended range and operating parameters, radar bistatic with combat aircraft (support sends, combat receives); improved ELINT sensors; improved EW and ESM	ONBOARD CARRIER AIRCRAFT: Extended range operations; aircraft size and weight growth if include extensive battle management operations on aircraft	All currently in work, will become available over mid-90s to 1st-generation new-type carrier
PROCESSING: Extensive processing at sensor; multisensor integration; advanced fusion of multisource inputs; extensive, AI inferencing about threat; asset use optimization	OFFBOARD CARRIER (aircraft or spacecraft): Could significantly reduce or eliminate pressure on carrier air wing aircraft growth; raises command and control issues for BG/BF commander	
COMMUNICATIONS: LPI/LPD, multimode	PROCESSING OPTIONS: All on aircraft or divide signal processing and further information processing to use sensor outputs between aircraft and ship to optimize communication/payload distribution	

ONBOARD AIRCRAFT: New carrier aircraft becoming available (e.g., ATS class), which may use A-X, improved S-3, or new air frames as replacements for various versions of A-6, E-2, S-3	Noted above	Same as above
OFFBOARD AIRCRAFT: Conventional long-range aircraft for offboard support (e.g., variants of E-3, P-3 classes)	Insufficient time on station to support carrier 24 hrs/day at remote locations, unless very large force (e.g., 7-10 aircraft per 24-hr station)	Now through 1st decade
HALE: Very high altitude (e.g., 100,000 ft), very long endurance (e.g., days) unmanned aircraft—e.g., w/200,000-lb gross wt. ~200-ft wingspan, 2000-lb sensor payload; aircraft can grow for larger payload	Land-based. With refueling from carrier (or land-based tankers) time on station limited only by reliability; space-type (years of service) reliability can be incorporated in payload and aircraft, processing on carrier and other ships as with ground stations for spacecraft; can be over/in range of battle force indefinitely, with much smaller force than conventional offboard aircraft	Mid term for operational system
High-performance rotorcraft (e.g., folding rotor; tilt rotor; other variants)	Enables airplane-like performance with capability to hover, for missions including ASW, tanking, cargo (COD), and rescue; allows operations without catapult, arresting gear, on smaller ships as well as large carriers	Now to mid term

TABLE 6.3 Key Advances in Aviation Weapons

WEAPON CATEGORY	SIGNIFICANCE	WHEN
AIR-TO-SURFACE BOMBS: New family of free-fall bombs including inertially and/or GPS-aided simple guidance, and enhanced warheads	More accurate and effective close-in bombing with safer delivery tactics (e.g., toss vice dive), using advanced attack aircraft avionics described in Table 6.1	Mid-90s
AIR-TO-SURFACE STANDOFF MISSILES (also includes standoff glide bombs): Multimode guided lock-on after launch weapons with ranges varying from 5 to 100 km; guidance could include GPS/inertial and/or multimode seekers (e.g., ARM+IR or TV) with or without data link; ultimately could include automatic target recognition	Allows attack aircraft to stand off from targets and therefore to evade close-in defenses; usable against area defenses as well as primary targets; permits weapon launch against accurately known location* or into a "basket" with sensor lock-on when target is in view; enhances economy of force, reduces aircraft losses, increases rates of target kills in campaigns	Mid-90s through mid term

LONG-RANGE CRUISE MISSILES: Ranges in 100s to >1000 km; guidance as above; can be air-, ship-, or submarine-launched; systems can incorporate stealth to penetrate defenses	• Aviation and space-aided for targeting* • Allows long standoff attack for defense suppression and destruction; allows stealthy attack against important primary targets • R&D and large-quantity buys needed to minimize costs	Available now in Tomahawk; advanced missiles could be available 1st decade or for mid term
AIR-AIR WEAPONS: More range and off-boresight forward aspect for follow-on IR weapons; multimode guidance for advanced EM-guided weapons; all weapons, improved aerodynamic (range, maneuverability) performance in smaller packages	More countermeasure resistance; higher P_ks; fit into internal aircraft bays better, allowing more weapon carriage in available space	Mid-90s to mid term
CL-20-based explosives and propellants	2-5X burn rate over current HMX, at expense of increased risk. Allows more flexibility to trade explosive power vs. stability by burning at reduced pressure (HMX is at limit). Means reduced size and greater range for rocket motors, smaller weapon warheads (and therefore more weapon range) for same explosive power	Mid-90s
Insensitive munitions	Greatly reduced hazards to carrier in event of hit	Near to mid term

*Detailed prior mapping of potential target areas in GPS coordinates needed for all attack missions using standoff.

TABLE 6.4 Selected Carrier Ship Technology Advances

DESIGN FEATURE	COMMENTS ON TECHNOLOGY AND SIGNIFICANCE	WHEN (if applic.)
NIMITZ-class monohull	• Hydrodynamic design near ideal; power per ton of displacement minimal at this size (~3.5 SHP/ton, cf. W/DD at ~11 SHP/ton), speed increase requires power as complex power function of speed (increases faster than V^3) • Very stable—"98% operable 98% of time in 98% of seas" • Must park and perform organic maintenance of most of air wing on flight deck; hangar deck too small for inside storage of total air wing • Large signatures in wake, radar, IR, acoustic, electromagnetic regimes • Many additional survivability problems—total survivability question discussed under "design drivers," Chapter 7	
The island	• Used for viewing operations, conning ship, carrying antennas • Minimal island required for antennas (and for stack gases on fossil-fuel-powered ship)—discussed under "survivability," Chapter 7	Significant change only in major ship modernization or new-generation replacements

Torpedo protection	• Adequate side torpedo protection in NIMITZ-class hull • Bottom torpedo protection inadequate; ship "box beam" subject to breaking under bubble load from large, wake-homing, under-keel torpedo; damage can include propulsion misalignment; explosion of magazines; electronic system shock damage • In current CVNs, can trade design functions for space to add protection—e.g., redesign and reduce magazine, shrink air wing • Can build torpedo protection into new large monohull in two ways: solid underkeel structure, or ship-length compliant water-filled structure with surge tanks to absorb explosion • Latter preferable if feasible, because could be collapsed to enter harbors and adds more damage resistance for weight used • Added protection will increase at-sea draft and lead to larger, heavier ship	Near term
Reactors	Current reactors of old technology—safe, reliable, increasing time between refuelings; new technology can include higher power density with safety, making ship volume available for other purposes including improved survivability	Mid to long term
Propellers	Currently WW II vintage; early-cavitating, distinctive signature; can be made quieter (later-cavitating, and might run deeper with some ship designs); especially interesting with electric propulsion or semisubmersibles	Near to mid term
Electric propulsion	• Major advantage in separating propulsion power from other ship power needs • Podded propulsors allow moving propellers out of ship boundary layer, alignment with flow, counterrotating tractor propellers—all enabling delayed cavitation and reduced acoustic signature, and finer control of maneuvering; price is larger ship envelope or complication of retractable propulsion pods • Benefits depend on progress in power storage, conditioning, and extraction and in cryogenics (including controlling effects of cryogenic damage and loss)	Mid term, with appropriate R&D

Electric catapults and arresting gear	• May save space and volume • Eliminates vulnerabilities of steam piping; adds those of energy-storage systems • Eliminates large elements of acoustic and IR signature, at expense of electromagnetic signature and EM interference to be suppressed • Allows feedback of power from arresting gear to catapults • Depends on progress in power-storage devices (capacitors, flywheels, homopolar generators), power extraction, and conditioning	As above
Night/bad-weather aids to aviation operations	• Improved landing and deck-handling systems would enable around-the-clock operations without slackening pace	Near to mid term
Electrodynamic armor	• Strong electromagnetic charge that senses incoming shaped charge weapon and discharges to break the jet and destroy the utility of its energy • Applied selectively	After appropriate power conditioning, below
Advanced power conditioning	• Advances in AC-DC conversion, power storage, regulation essential for separation of ship's power from ship's propulsion, for electric catapults, DEW, other high-power uses, and advanced avionics maintenance and setup • Is the pacing item for most of applications noted	Mid to long term
Skijump	• Depending on design and aircraft T/W, can enable takeoff without catapult, or if catapult-aided, with significantly smaller catapult; concern expressed by operating community that steep (>3°) skijump, if large enough part of ship length, would preclude essential aircraft parking on forward deck area • Modest skijump (14 in. high by 42 ft long, 2.1°) forward of catapults can reduce wind-over-deck requirement for current aircraft by up to 24 kts • Aid to STOVL takeoff by eliminating catapult requirement; can be used with catapult to control deck configuration and operability	Near term ("know how" now)

Fiber-optic internal ship communications	Enables sturdy internal network, highly resistant to single-point failures; eliminates signature from RF emanations from conventional communications	Available mid-90s
Semisubmersible hullforms (e.g., SWATH and variations)	• Completely modifies signature (virtually eliminates turbulent wake from propellers, which can run deeper; can use submarine technology for propulsion and quieting; IR, RCS changes different than for monohull) • More damage-resistant (can use double- or triple-hull submarine construction for hulls; much of hulls and pylons filled with ballast and compartmented; reactors, magazines shielded from air-surface missiles; more of larger flight deck available to work around damage) • Large ship (NIMITZ-size deck) has internal hangar space for 86 A/C wing, enabling further signature reduction by moving aircraft (and much yellow gear) off flight deck for parking and servicing • Draft and displacement interact strongly: for flight deck 1100 ft by 250 ft, ~325,000 tons empty with 40-ft draft for harbors; ~660,000 tons ballasted to run with propellers at 125 ft; requires ~4X NIMITZ power for 25-knot speed • Larger flight deck means lower wind-over-deck requirement, speed needed only to deploy; wide, full, rectangular flight deck makes available "parallel" runways for side-by-side landing and takeoff operations or interleaved, high-rate landings and takeoffs; could compensate for any loss of operating frequency caused by all-inside parking and turnaround • Smaller (LHA) size has greater steadiness than monohull in heavy seas	1st generation for small (35,000 to 50,000 ton) carrier; 2nd generation for large (>100,000 ton) one (either one requires extrapolation from current 3500 ton experience)

TABLE 6.5 Generalized Radio-electronic and Acoustic Sensing and Battle Management Advances

TECHNOLOGY ADVANCE	SIGNIFICANCE	WHEN
Airborne sensors: See Avionics, Table 6.1, and Support Aviation, Table 6.2	• Longer-ranger, I O sensing with advanced focal plane array IR sensors (in appropriate atmospheric conditions) • More accurate radar target position sensing with higher EW resistance and counterstealth features • More rapid ELINT sensing and interpretation • Weight growth but more stealthy operation • Increased system reliability	90s for IR 2000 to 2010 for other
Carrier phased array radars	• Counterstealth improvements, based on AEGIS-like improved planar electronically scanned arrays; can put such radars on carrier; will need steps to shield A/C and personnel on flight deck from full power operation of large radars in SPY-1 class • LPI/LPD characteristics of close-in air traffic control radars if separate from above	Near term
ASW: Active acoustic, advanced passive systems vs. quiet submarines; onboard arrays vs. torpedoes	• Will continue a measure of own-ship protection vs. hostile submarines, in parallel with surface ship torpedo defense; will enhance latter • Will enable other battle group ships to recapture ground lost when submarines became quieter, to add to carrier protection	Near to mid term

Cooperative engagement	• Enables all ships and aircraft in battle force to contribute to overall AAW threat and defense picture; implies multisensor integration, automated weapon allocation, and optimized use of all battle force weapons in battle	Building gradually now
Advanced computing in smaller and lighter packages	• Enables efficient shipboard processing and integration of airborne and space-based sensor readouts • Enables rapid threat evaluation based on multisensor integration • Enables commander to evaluate alternate courses of action rapidly through "what if" modeling and battle simulation onboard ship	Building gradually now
Advanced communications	• Enables LPI/LPD communications among all participants in battle force activities, with requisite bandwidths and with high degree of security from detection and exploitation and anti-jam capability; is the pacing item in cooperative engagement and ability to alleviate weight penalties of large battle management loads on aircraft, attending sensor advances, by shifting the load to receiving stations aboard ship	Building gradually now
Advanced displays	Enables conveying outputs of complex processing and computations in simplified, easily manipulable form for rapid assimilation and change	Building gradually now

TABLE 6.6 Carrier Self-defense Armaments

APPLICATION	DESCRIPTION AND SIGNIFICANCE	WHEN
Improved CIWS	• Larger caliber; more responsive to maneuvering threat at somewhat larger range; this and next system listed "must" for high-speed sea skimmers and leakers from high-altitude attackers; must be on carrier	2000 to 2010
Improved antiaircraft missiles including ATBM capability	• Improving NATO Sea Sparrow, augmenting it with Rolling Airframe Missile to increase firepower; fire control functions, similar to AEGIS, but simpler; tied in with AEGIS • New missile, Sparrow-size or somewhat larger (600-lb class), hit-to-kill for ATBM, less constrained trajectory for other threats • Missiles can be in VLS bays at deck edge • Also applies to total ATBM protection from other combatant accompanying carrier if attack and intercept trajectory interactions permit • SDI terminal defense missile may be adaptable as interceptor	Near to mid term, with missiles improving over time with appropriate R&D
Directed-energy and electromagnetically driven, hypervelocity kinetic-energy weapons	• Highly desirable for response time • Could be high-energy lasers, charged particle beams, or electromagnetic guns (coilguns or railguns) • Constellation of fundamental problems in physics, power generation, beam stabilization, fire control, and guidance to be solved, depending on which approach is chosen	Mid to long term with vigorous R&D program; laser weapons are nearest to feasible application

Low-yield nuclear warheads	• For use against targets violently maneuvering in terminal phase, or against incoming warheads that must be destroyed (e.g., nuclear)—technically feasible; development and use subject to policy determinations	Can be made available near to mid term depending on battle space requirements
Active torpedo defense	• Requires detecting, tracking, and intercepting incoming torpedoes; must be carrier-mounted; feasibility not in doubt, but signal/noise problems to be solved to keep false alarm problems at tolerable level	Near term
Mine defense	• Requires airborne mine-hunting system so carrier can avoid minefields; might use lasers for search, detection • Rising mine a serious problem to be addressed by passive and active acoustic systems on carrier; may require a combination of "soft" and (very high speed) "hard" kill	• Near to mid term • Mid to long term
Advanced seeker and guidance technology	• Similar advances to those for air-air weapons, Table 6.3	Same as for Table 6.3

TABLE 6.7 Human Factors, Supportability, Sustainability

TECHNOLOGY OR APPLICATION	DESCRIPTION AND SIGNIFICANCE	WHEN
Modern selection, classification, and assignment techniques	Increased productivity of available crew members; one factor in potential crew reductions	Available now; can enter carriers near term
Improved habitability	• Divides personnel spaces into housekeeping modules, with many simplified and automated housekeeping and health functions; fewer (but not elimination of) large-group messes and some functions • More efficient use of space; automation of functions now requiring much human intervention, permitting crew reduction without reduction of <u>necessary</u> functions or redundancy	Available now; can enter carriers near term
Embedded training	• Systems include simulation modes usable for training and exercises • Allows unit training while ship is deployed and operating; allows training in multiunit groups, and with other ships in battle group, assists in maintaining proficiency and readiness while saving costs of predeployment training	Incorporated in many systems today; can be incorporated in all future systems
Rationalized logistics and manpower engineering	• Automated maintenance functions; computerized maintenance aids; ergonomic design of systems to be maintained, maintenance machinery and tools, suited to crew handling; automated off- and on-aircraft troubleshooting; automated sensing and positioning of yellow gear when moving about deck; rapid manufacturing of some spare parts • Modular turnaround and maintenance on assembly-line principle—aircraft move station to station for mission preparation or organic maintenance; extensive use of robotics and computer-aided equipment • Use of computers and CD ROM for all manuals and paperwork; even with necessary redundancy "paperless ship" implies savings of ~350 tons of paper and up to 10,000 ft^3 of storage space • Enables condition-based maintenance, resupply on demand, quicker turnaround; translates into more sorties and longer sustainability, smaller crew for necessary tasks	Available now, improvements continual, can enter carriers as ready

"Instrumented ship" for damage control; automated damage control functions; ship condition monitoring for maintenance	• Saves time and casualties by indicating location and extent of damage; especially enables "visibility" on ship through smoke and in inaccessible compartments • Automated functions include those where crew would not be endangered but damage control and correction would be speeded and/or safer; must include manual work-around in case equipment disabled • Helps in monitoring maintenance functions aboard ship, and leads to more efficient "just-in-time" operations, smaller parts inventories, and fewer failures caused by lack of attention • Contributes to counterterrorism in port	Available now, improvements continual; can enter carriers as ready
All-electric yellow gear	• Would eliminate need for auxiliary hydrocarbon fuel; would facilitate operations without opening hangar deck, reducing signature; reduced IR signature from yellow gear on flight deck • H_2 for fuel cells made onboard from seawater, using reactor power (also, liquid oxygen for aircraft and flight operations) • Alternatively, high-energy-density batteries	Mid term
OVERALL SIGNIFICANCE OF CHANGES------------------->	• Crew size could gradually be reduced without reducing combat and damage control functions or capability • Can reduce casualties and ship downtime by hours to days in case of damage; can increase ship survivability by reducing signature; if volume saved on personnel can be recovered efficiently, can make additional ship volume available for diverse survivability or sustainability purposes (e.g., improved torpedo protection; more self-defense weaponry; increased tankage of aviation fuel) • Calls for development of system concepts using these capabilities to establish priorities and patterns of design in application to carrier system overall	From above; much near term; most by mid term; full implementation by long-term carrier generation

7

CARRIER DESIGN DRIVERS AND IMPLICATIONS

There are three main classes of "drivers" of future carrier design:

1. *Trends in aircraft technology;*

2. *The need to enhance survivability* of the carrier in its future operating environment; and

3. *Other technological advances* that can make for significant efficiencies in carrier system design, that can mitigate the adverse effects of the above two "drivers", and that can lead to new carrier system concepts.

These design drivers and the questions they raise for carrier design and operation are discussed below. Several different kinds of carrier designs that might be conceived to resolve the critical questions and to capitalize on the new technological opportunities are presented and discussed in Chapter 8.

TRENDS IN AIRCRAFT TECHNOLOGY

Trends in aircraft technology determine the size and design of the flight deck and therefore determine much about the size and design of the carrier as a whole. These trends are moving in three directions: increased size and weight of CTOL aircraft, enhanced performance of powered lift aircraft, and increased versatility and utility of unmanned aerial vehicles.

Size and Weight Growth of CTOL Aircraft

The total weight of the carrier aircraft complement depends on the composition of the carrier air wing and on the size and weight of the individual aircraft within it. Total weight can be taken as an indicator of the average trends in aircraft design through the years. It began to grow with the advent of jet aircraft, from about 1 million lb in 1950, before the first

carrier-based jets, to just under 5 million lb in 1978. It has grown only very slowly since then.

The heaviest aircraft now operating from a carrier is the F-14, with a maximum takeoff (combat loaded) gross weight (TOGW) of 68,000 lb and a maximum landing weight of 54,000 lb. The landing weight stresses the arresting gear to the design limits. The largest aircraft is the E-2C; it just fits under the 26.5-ft overhead of the hangar deck. Potential future drivers are the next-generation fighter, attack, and advanced tactical support (ATS) aircraft.[1] The fighter and A-X may extend aircraft spotting factors by a few percent, stressing the current space allocations. Early design studies indicate that some configurations of a single ATS aircraft might stay within the E-2C envelope but that it could have significantly larger takeoff or landing weights than the F-14. Depending on the configuration, the advanced tactical support aircraft variants could weigh up to 100,000 to 125,000 lb, fully combat loaded, with landing weights up to 80,000 lb. Historically, all aircraft have grown in weight during their service lives. There would be no reason to expect this trend to change, so that the weights anticipated for initial models of the new aircraft would increase through successive improvements. The current design limits for catapults, arresting gear, and aircraft storage space would certainly be exceeded if these trends were to continue.

The trends are driven partly by the need for increased range, for access to some key littoral and hinterland areas where strike warfare may be necessary, for provision of adequate standoff from hostile shores where improving weapons systems threaten carriers from longer ranges; and for the outer air battle against the Soviets if a threat from that direction reemerges. Another driver is the need for increased payload, brought about mainly by the need for sensors and weapons to deal with stealthy systems. Of special concern are radar antenna size and design against low observable threats, some of the EW and electronic intelligence (ELINT) equipment for AAW and strike warfare, and sonobuoys and weapons for ASW missions. Thus the ATS function heavily influences this trend. Adding to the complexity of the

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[1] Although the future of these aircraft is undecided, as of the spring of 1991, the coming end of service life of the aircraft they would be replacing, during the decade 2000 to 2010, and the need for an aircraft to replace the A-6, suggest that the next generation of carriers will have to deal with such aircraft early in their lifetimes unless the growth trends are modified by some of the alternative approaches discussed in this report, or other approaches. The term "advanced tactical support (ATS)" is used here to connote the function as well as any new aircraft—one or several—that will be acquired to perform it.

design problem for this aircraft has been the desire for a single airframe to carry out all the support functions (which also include midair refueling and COD), to reduce the number of airframe types aboard the carrier, and thereby to ease acquisition costs and maintenance burdens.

To adapt to the coming prospect of aircraft growth and its effects, some adaptation of carrier and aircraft design and operations will be necessary: the carrier can be changed within the NIMITZ-class envelope; aircraft landing speeds can be reduced; the carrier can be made larger; or significant functions that are drivers of the growth can be carried out in a different manner.

Solutions to Aircraft Size and Weight Growth Problems

Adapt to Current Trends

Although the specific ATS concept of a multipurpose airframe for tactical support missions has not yet proven acceptable, the factors that make for larger aircraft for the missions remain. It would be very desirable to stay within the NIMITZ-class envelope to keep ship costs down and to avoid exceeding the bounds of port depth and drydock facilities. Current aircraft gross and landing weight operating limits of the carrier can be extended by a number of means.

Catapult capacity can be enhanced to enable launch of aircraft up to 100,000 lb. An increase of ~15 percent in the wind-over-deck requirement for launch, together with an added 50 ft of catapult length, could enable a 100,000-lb launching weight. A modest skijump (e.g., 14 in. high and 42 ft long—Table 6.4) added to the forward edge of the flight deck, forward of the catapult, would significantly reduce the need for these steps. There may be some question as to whether this addition would interfere with aircraft handling and parking, but extending the catapult would also mean moving the jet-blast deflector, and so would start a chain of design changes.

Enough additional landing length (100 ft) for an aircraft 12,000 lb heavier than the F-14 at landing can be made available by eliminating the forward, fourth wire of the arresting gear system and allowing a longer runout, to the limit of 35 ft from the landing deck leading edge that is accepted on the FORRESTAL, compared with 95 ft on the NIMITZ class. To reach an 80,000-lb landing weight, the landing speed of the aircraft would have to be reduced about 7 percent; this might be done by elaborate wing flap design and/or vectored thrust, as described in Table 6.1, but at a penalty

in useful load that would have to be determined; it could be as high as 10 to 12 percent. A stronger arresting gear (toward which the Navy is moving) would allow more deceleration in stopping the aircraft, provided the aircraft could accept the added load. Eliminating the forward arresting wire could require means (such as a "smart hook," "smart wires," or "smart" thrust and aerodynamic controls for more precise glide path control) to compensate for any significant reduction of hook engagement probability during landing, especially in adverse weather.

Restrain the Weight of Combat Aircraft

While the ATS function appears to be the most stressful in terms of aircraft size and weight growth, the desire for more range and payload performance also affects the size and weight of the new generations of combat aircraft being contemplated. This can exert pressure on available carrier launch, support, and recovery facilities as well. The size and weight of these aircraft can be constrained by some changes in the weapon complement of the aircraft. Such changes are encouraged in any case by the need for internal weapon storage to reduce radar observability; the choice is to let the aircraft grow to carry previously typical weapon loads, or to change the allocation of useful load between weapons and fuel for range.

The allocations between fuel and weapons in the range and payload envelope would have to be viewed differently, using guided weapons more and large weapon loads less for anticipated target kills per sortie. This is not necessarily an adverse penalty, because such a change in weapon mix would, in any case, lead to greater economy of force against concentrated targets (which constitute the vast majority). It implies guided rather than free-fall weapons in large numbers for strike warfare. Analyses show that although individual weapon cost would be higher, overall system cost and time to destroy a target complex would be made lower by the reduced need for "revisit" sorties and reduced aircraft losses, particularly if many of the static or fixed targets were attacked using standoff weapons. "Level-of-effort" area bombing of some targets with free-fall weapons, for which such bombing is needed, might have to use other means, as did the B-52 LINEBACKER II campaign of December 1972 in Vietnam or the B-52 strikes against the Iraqi army during the air campaign of Operation Desert Storm.

Increase Ship Size

If such adaptations prove unsatisfactory, and if it is still essential to allow the aircraft to grow, then the ship will have to grow as well. An 80,000-lb aircraft landing at 150 knots needs a 500-ft runout, compared with the 340 ft available today and the 440 ft that can be achieved as described above, leaving an additional 60 ft to be gained. The angled landing deck cannot be extended without extending the flight deck length as a whole (the angled deck can be no longer than three-fourths the length of the full flight deck) without raising the questions of stress limitations due to slamming in high seas and crane clearance in the present building docks.

Ship designers have indicated they would be most comfortable with an additional 100 to 125 ft of flight deck length to accommodate the new designs they are seeing. Ordinarily, other dimensions would grow accordingly to preserve the same hull shape, leading to a ship displacing about 135,000 tons. (Ship growth could also be required by extension of the passive torpedo defense structure, described below in the section titled "Survivability"; the growth for that purpose would provide more than adequate space to handle the largest CTOL aircraft foreseen.) It might be possible, however, to extend the NIMITZ-type hull by 100 to 125 ft without changing other dimensions. This would lead to a ship displacing 105,000 to 110,000 tons with a slight decrease in speed (one knot or less), but it would lead to survivability benefits to be discussed below. All of this implies a "stretched NIMITZ" or a new class of ship, in which it would also be easier to incorporate many of the available signature reduction measures and other engineering advances discussed below.

It is important to remember in this connection that any new aircraft that would otherwise force growth in new carriers would also have to operate from the remaining NIMITZ-class ships. Conversely, if the carrier were to grow for other reasons it could accept larger aircraft, but the NIMITZ-class ships would still have to be served.

If the need for aircraft and ship growth were accepted, this would mean that the new aircraft systems would have to be timed to meet the first mid-term carriers, in about 2005 to 2010. Realistically, at this point, only the later ships in that group (those commissioned after 2010) could be slated to receive *ab initio* an aircraft whose development could not be started until 1995 at the earliest. If the new aircraft were too large to operate from the NIMITZ-class ships, it would operate only from the larger mid-term ships, and some solution would still be necessary to extend the combat capability of the NIMITZ-class ships. That might be done with a lightened version of

the new aircraft, but this would be a complex task; the aircraft would have to be designed to be light and then allowed to grow into a version operable only from the new carrier. It might have significantly different capabilities in the two cases, in view of the critical ATS aircraft design drivers (e.g., weight of the AEW radar), leaving a different overall combat capability in different carrier air wings.

Increase Reliance on Offboard Surveillance and Targeting

An area of potentially great gain in modifying the carrier air wing to accommodate extended combat system range requirements is to rely more on offboard surveillance and targeting systems.

If the combat information network must extend the carrier's offensive and defensive battle space while growth to accommodate increasing weight of the ATS aircraft is limited, then the alternative is for the battle group to shift some, and perhaps much, of its reliance for surveillance and targeting data from onboard to offboard information sources.

A critical issue for the battle group commander is the enduring concern that the offboard assets (spacecraft and long-endurance aircraft, manned or unmanned) will not be available when needed. If the assets were kept under the direct control of the battle group commander by making them "organic" to the battle group, no matter where they are based, then he would "own" extensive onshore and even space-based facilities and systems. His span of control would be greatly expanded, and new command relationships with regional CINCs and sometimes with other armed services might have to be worked out. Also, a 1988 classified report of the Defense Science Board showed how the needs of the tactical commander could be met and protected with assets that may be under the partial control of the national system for space assets.

As implied in Table 6.2, conventional approaches to offboard aircraft support can be useful when safe land bases for their operation are within reasonable range of the carrier operating areas. If these distances become large, shortcomings associated with their relatively limited range and endurance will become important. In addition, aircraft fleets of substantial size might be needed to provide the necessary coverage; for example, it could require seven aircraft in the force to ensure that one AWACS-type aircraft provides 24-hr coverage to a battle force operating in ocean areas distant from the aircraft base.

Different alternatives are to change the nature of the surveillance assets. Space systems have been noted above. Unmanned high-altitude, long-

endurance (HALE) systems offer one new approach; lighter-than-air craft might be thought initially to offer another.

Lighter-than-air craft can be made large enough to carry the desired antennas to detect low-observable targets. Their endurance can be indefinite. They must operate at fairly low altitude, however, which makes them more likely to signal the presence of the battle force, and which makes them vulnerable to damage or loss in severe weather. For this reason they have been ruled out as an option for this mission.

HALE systems could be built much as space systems are built today, in terms of long-term reliability, and they could be designed and operated in such a way as to be available to and under full control of the battle group commander at all times. The payload limitations of such aircraft would preclude carrying radars able to resolve fully the problems of detecting and tracking stealthy aircraft and missiles below some signature thresholds. The threat detection problem would have to be partitioned such that the offboard systems could detect and track threats above these thresholds, while those below the thresholds would have to be left to the close-in surface-based defenses of the battle group, including those of the carrier. The HALE aircraft with radar systems foreseen today could usefully contribute cueing information to the self-defense systems.

The HALE aircraft characteristics listed in Table 6.2 represent a first-generation system. Future generations of HALE aircraft could be designed as larger aircraft to carry larger payloads, improving our effectiveness against stealthy targets. These aircraft could become as heavy as the large transport aircraft that carry land-based AEW systems, but given their endurance and the reliability the needed fleet of aircraft should be significantly smaller.

Small, single-purpose satellites for some *ad hoc* surveillance and communications missions could also be launched by ships in the battle force if necessary.

These changes do not have to be "all or nothing." If it were deemed critical to keep the carriers from growing larger than the NIMITZ class, it could be decided to achieve the best feasible onboard surveillance and other support capability within the scope of airframes that suit the ship. Shortcomings of those systems could be remedied by augmenting them with the offboard assets; this is done to a significant degree today. If it were desired to shrink carrier size (as in one of the carrier options presented in Chapter 8), and if the onboard surveillance and support aircraft were the critical element prohibiting that, more or most of the capability would have to be shifted offboard.

Powered Lift Aircraft

The high-performance F/A-18-sized STOVL fighter/light attack aircraft described in Table 6.1 is made feasible by the continuing trend to engines with increased thrust-to-weight ratios. Those engines have been developed in part to make the range- and signature-reduction benefits of supersonic cruise without afterburner feasible in conventional combat aircraft. If the gain in thrust-to-weight ratio is turned toward enabling reduced takeoff run of a combat-loaded aircraft and vertical landing of such an aircraft after its combat load is expended, the resulting STOVL design could operate from an LHA or LHD as the AV-8B does today, or from any other platform large enough to accommodate the modest takeoff run and vertical landing, as well as from the large deck of a NIMITZ-class carrier.

The weight penalty of the aircraft in a single-engine version under today's rules of safety and risk is, as has been indicated, modest. The 5 percent penalty can be accommodated by judicious allocation of the useful load, as has been described for the advanced CTOL combat aircraft, above. Today's rules for single-engine-out performance during launch and recovery would require cross-shafting in a two-engine aircraft, increasing the weight penalty to an unacceptable 20 percent. This could be alleviated to achieve a lighter twin-engine aircraft of this kind by relaxing the rules for cross-shafting. The risk of losing an aircraft due to failure of a single engine at a critical time would then be increased, while the risk of losing a single-engine aircraft at another time during a mission would be reduced. The trade-offs would have to be examined as part of the design analysis preceding acquisition of such an aircraft, and the risks weighed against the benefits of having an aircraft that can perform different missions in different parts of the fleet.

From a smaller carrier or amphibious assault ship, the STOVL aircraft with its supersonic cruise capability could be used as part of a mixed carrier battle force to contribute to the air defense screen of the large carrier, and as fighter support for amphibious landings. A smaller carrier with STOVL fighter/attack aircraft could operate independently in scenarios not needing the full attack and defense capability of the large carrier. It could receive additional protection when needed by CG-47- or DDG-51-class ships. It would also need support by offboard assets for surveillance, reconnaissance, and EW support, of the same kind that was discussed for the large carriers (it could be supported to some extent in these missions by onboard unmanned aerial vehicles [UAVs]).

The aircraft could be especially useful on a large carrier as well. It would offer the advantages of more rapid flyout to meet incoming threats, of being able to operate from flight decks having bomb damage or catapult and arresting gear outages due to damage, and of being able to sustain high operating rates because more than one such aircraft could land on the large deck at once.

The high-performance rotorcraft listed in Table 6.2 can be considered hybrids that are partly fixed wing and partly helicopter. Although some designs of such aircraft would entail some penalties in comparison with helicopters in hovering, and all of them would pay some performance penalty in comparison with conventional fixed-wing aircraft in forward flight, the combination in one machine would offer many compensating operational advantages. They would be considerably more efficient in hovering or slow-speed flight than would fully fixed wing VSTOL or STOVL aircraft, and they would be considerably more efficient in horizontal flight than helicopters. They would be especially useful for ASW, from large or small ships. They would have larger payload, speed, and range than helicopters, allowing more search area, more sonobuoys and weapons, and more rapid follow up of contacts by ASW forces. They could supplement and possibly supplant the aircraft designed for the ASW part of the ATS function. They could also be used for COD and rescue purposes, and in appropriate versions, for air-to-air refueling. They would offer the same advantages as the STOVL fighter in terms of operational flexibility from large or small carriers or air-capable ships, especially in case of battle damage to a carrier's flight deck.

The availability of the STOVL fighter, together with the high-performance rotorcraft, would make possible a smaller, albeit less capable, carrier option that, in a mix with NIMITZ-class and subsequent large ships, could provide a high degree of flexibility to the carrier force as a whole. *It should not escape notice, however, that the gains in fleet flexibility and any potential savings in initial ship cost from going to the smaller carrier must be considered together with the cost of developing these new aircraft. The ship cost per embarked aircraft for the smaller carrier would be significantly higher than the comparable cost for the large carriers. The aircraft, on the other hand, can be useful from any aviation-capable ship, so that their acquisition cost alone should be considered separately from that of the ships.*

SURVIVABILITY

Threats and Directions for Solution

Together with the battleship, an aircraft carrier is the sturdiest ship in the Navy, able to absorb considerable hostile fire without sinking. However, available studies show that hits on a carrier by one to three or four large air-delivered weapons, such as the 500- to 1000-kg warheads of some of the potentially opposing cruise or ballistic missiles, can put it out of action for significant periods and make it more vulnerable to a killing attack. As noted above, it is also vulnerable to having its propulsion machinery seriously misaligned, its magazine exploded, and/or its back broken by torpedoes designed to explode under the keel. Despite the multilayered defenses designed to minimize the chances of a hit, it must be accepted that a determined enemy will be able to land hostile fire on a carrier.

Carrier signature is involved in detecting the carrier and in targeting it for weapon delivery. A carrier's general location in a crisis area will likely be known; indeed, it will probably be announced as part of the crisis management. Large signatures will enable any capable enemy to locate the carrier and identify it well enough for targeting. Extensions of Soviet bomber-launched cruise missile ranges have been reducing the battle group's ability to intercept and destroy or deflect long-range bomber-type aircraft before they can launch their attack missiles. Extension of such difficulties to threats other than the USSR depends on the kinds of missilery and long-range aircraft they can acquire.

In Third World littoral-area operations, hostile tactical aircraft could be intercepted much more easily from a carrier. But if threat attack aircraft, or disguised transport aircraft or cargo ships, are able to launch long-range missiles, or if there may be the possibility of neutral aircraft or cargo ships requiring visual identification under some rules of engagement, missile launch by hostiles between the time of detection and intercept of approaching aircraft or ships would be feasible. The ballistic missile and submarine threats—the latter including torpedoes and high-speed sea-skimming missiles—have already been noted. Over the life of the ship, many weapons are likely to become stealthy, or very high speed, or some combination, reducing the carrier's defensive battle space and making defense of the ship from outside its own defense perimeter more difficult. In some combinations of circumstances simultaneous attacks by large numbers of weapons from different types of launchers would be feasible.

Protection of the carrier includes both *passive* and *active* defense. *Passive defense* includes reduction or complete modification of the carrier's signature to make targeting and weapon guidance more difficult, and increasing the ability of the carrier to resist damage and to recover from damage if it is hit. *Active defense* includes intercept of threats by the carrier's own aircraft before threat aircraft and submarines can launch their weapons; defense by offboard AAW and ASW systems that may be part of the battle group or that may be more distant and under other (battle force, joint, or unified) command; and ship self-defense against incoming missiles that may leak through or are launched from inside the aircraft defense perimeter, and against torpedoes.

The various approaches to defense of the carrier are taken up in turn, below. The integrated effects on carrier design are then considered.

Passive Defense

Detectability, Signature Reduction and Modification

A carrier has large signatures in several domains. Radar signatures derive from the shape of the carrier, the presence of resonant cavities opening to the outside of the ship, and the presence of aircraft and support equipment ("yellow gear") on the flight deck. There are infrared signatures from the many heat sources on the ship and its air complement. The turbulent wake of the carrier is long and subject to detection at long range, including from space; the wake from the bow and stern waves can be similarly detected by appropriate techniques. Much carrier activity and onboard machinery including catapults, and ship propulsion systems including propellers, create recognizable, carrier-specific acoustic signatures. Electromagnetic radiation from radars and communications associated with air operations, battle force operations, onboard operations, and ship defense can enable detection, classification, and location of the ship.

Current carrier radar and acoustic signatures are so large that location of the ship and weapon guidance against it are easily feasible. It is possible by appropriate design and treatment to disguise the radar signature of a carrier (e.g., NIMITZ size) to make it more difficult to distinguish from other ships and to facilitate decoying and masking by chaff and other electronic countermeasures (ECM). Aircraft and equipment on deck could contribute to radar cross section (RCS) in some unknown degree; it is possible to mask them from viewing at low angles, but they would be visible

during launch and recovery operations—les, so if they were stealthy to begin with—and from elevated angles. Masking at low angles could offer added protection against guidance by sea-skimming missiles.

The main contributors to a current carrier's acoustic signature are the propellers. Carrier propeller design is essentially of World War II vintage. Modern design and manufacture and deeper running can increase the cavitation speed and reduce the acoustic signature. Electric drive with the motors and propellers in pods would further increase the cavitation limits by aligning the propellers with the flow around the hull, enabling smaller diameters through counterrotating pairs, and using tractor propellers removed from the ship's or the pod's turbulent boundary layers. If the pods are suitably designed (and retractable for port entry), the podded propellers can also be run deeper than propellers on shafts penetrating the stern of the ship. Propulsion machinery can be treated in many respects in a similar manner to submarine machinery to reduce that component of acoustic signature.

The propeller changes designed to reduce acoustic signature would also reduce the component of the turbulent wake due to the propellers. This would reduce visual detectability in some measure, and it would reduce noise interference with ASW systems. The wake component due to skin friction would remain. Significant reduction of the wave component of the wake of a well-designed hull, which the NIMITZ has, would be feasible only by changing the hull design to reduce its water-plane area—that is, by going to a semisubmersible design (i.e., a SWATH and variations).

Significant reductions in infrared (IR) signature require cooling of hot spots and masking or fundamental design changes in large heat sources. Extensive use of high-peak-power machinery for such features as electric catapults and arresting gear and directed-energy or hypervelocity kinetic-energy weapons might reduce IR emissions but would carry its own electromagnetic emission signatures, which would have to be shielded.

Electromagnetic emissions from the carrier's radars are unique in current designs, and therefore are easy identifiers. They can be changed to appear like those of other ships by using the other ships' radars. In particular, a planar array, electronically scanned radar, based on the AEGIS SPY-1 radar, onboard the carrier could carry out all the search and targeting functions of its current radars. This radar will be under continual evolution in the battle force combatants, such as the AEGIS cruisers and the new DDG-51-class destroyers, to be able to deal with increasingly difficult threats. Different versions are likely to coexist, and one on the carrier with the same wave forms as those on the Battle Force Combatants (which will

be called the SPY-() here) could fit into the set. The remaining radars needed for close-in aircraft approach and landing control could be kept to low enough power to be undetectable from over the horizon, or the SPY-() could be made to carry out those functions as well. Use of an AEGIS-like radar on the carrier, even though its power output most of the time would be lower than that of the other AEGIS radars in the battle group, would also contribute significantly to its self-defense capability, as is indicated below. Use of such a radar at full power on the carrier would require solution of serious radiation hazards to aircraft equipment and personnel on the flight deck.

It might be argued that any ship with an AEGIS-type radar, which is easily detectable at long range, would allow the ship to be targeted easily and would itself be a lucrative target for antiradiation missiles (ARMs), so that not much would be gained by this step. However, the SPY-() radar on the carrier could be scintillated in a cooperative engagement mode with those of other ships in the battle group, with a time constant that would make lock-on and guidance by hostile weapons difficult.

Reduction of emitted electromagnetic signatures due to communications requires attention to antenna design, to communications doctrine, and to the design of the system of command, control, and information flow in the battle force as a whole. The technology will ultimately allow non-retroreflective planar antenna arrays to reduce antenna detectability, and LPI/LPD communications. Judicious system design, with attention to controlling bandwidths and directions of information flow to and from the ship, will be needed to optimize the design in this area.

Overall, the amount of change in the radar and IR signatures that would be possible with a NIMITZ-class design may be limited. Explicit design studies would be required to determine whether the reduction would yield enough in facilitated masking and decoying capability to warrant the expenditure. Larger ships may offer more opportunity for treatment and redesign to reduce radar and IR signatures. Propeller and some machinery noise and electromagnetic emissions could be controlled as indicated above. Design and construction of the island might be changed to reduce its observability. Such changes would attend installation of planar array radars (SPY-() and close-in target engagement radar, discussed below) and communications antennas, and would allow significant redesign of the island to reduce vulnerability to the effects of damage as well as ship signature.

Keeping all aircraft inside the hangar when they are not operating would not be feasible in any case for a monohull design of a size near that of the NIMITZ class and the current or planned future air wings. (Operations

"from inside" would require increased ship size to accommodate the aircraft, with changes in how space is used inside the ship; possibly some reduction of the size of the air wing; and much more frequent use of the elevators, including their use in heavy weather when aircraft and personnel could be endangered during transfer.)

Another, long-term alternative would be a change to a completely different hull design: a semisubmersible like a SWATH or related design. The signature implications of a semisubmersible design are seen, from the above discussion, to be large. First, the structure of the ship's radar signature is different from that of a monohull. A semisubmersible with a prismatic "bridge" between the pylons, and having a flight deck as large as that of a NIMITZ-class ship (roughly, 1100 ft by 250 ft), would be able to house inside all the aircraft of a current 86-aircraft air wing. Its wake would be reduced by virtue of its smaller water-plane area and because at sea the propellers would run at 100 to 125 ft in depth. Submarine technology would be used in the hulls to reduce the acoustic signature, including propellers and machinery. IR and electromagnetic (EM) emissions would be handled in the same way as on the monohull. Finally, this hull design would have significant implications for damage reduction, as discussed below.

Damage Reduction

Changes in design to reduce the damage due to a hit, and to reduce the time and effort necessary to control the damage and put the ship back in action, can be made in several parts of the system. Compartmentation can be changed to reduce the number of long passageways through which flame and smoke can flow. The passageways are now interrupted by closed hatches if the ship is at general quarters, but fire and smoke started by a surprise hit could propagate rapidly. The price for such changes could be serious inconvenience in moving about the ship when it is not secured. Materials that do not smoke and generate toxic gases on combustion, for mattresses and other soft equipment, would ease crew operations in damage control; such materials are available today.

Other steps to maintain functionality in case of hits include enhancing the armor protection of key ship elements, and relocating critical elements to less vulnerable places. Composite, layered steel-and-ceramic armors can be made more penetration-resistant for unit weight, and can be applied to areas such as the Combat Direction Center (CDC), Flag Command Center, and the magazines. The CDC and Flagplot can be relocated so that they are not immediately under the flight deck, and so that more of the ship

separates them from the surfaces that may be hit. Computer and display equipment inside those areas must be shock mounted to reduce breaking of display tubes and circuit junctions.

Current designs and manual operations often make it difficult to locate and isolate damage and fires, causing wasted time, increased damage as fires burn uncontrolled, and risk to damage control crews. A most important addition to the ship design, which could have a very large effect, would be to instrument the ship so that the locations and probable extent of damage can be determined from remote locations. This would have to be accompanied by a sturdy internal communication network not easily disrupted by fire and cut lines. A highly redundant fiber-optic network distributed through the ship would accomplish this, and would also eliminate radiated electromagnetic signatures from leakage of internal radio communications. Improvement of the tools for damage control, including such things as facilitated access to damaged areas, automatic quenching, denial of oxygen, means for rapid purging of toxic gases, and selected automatic or remote damage control machinery, such as pump controls, including application to the flight deck, could make damage control more efficient and effective over less time. Installations that monitor the ship's condition would also help in isolating areas requiring maintenance, so that the system would pay for itself by performing peacetime as well as wartime duties.

Current hull design of the large carriers provides adequate side torpedo protection through appropriate structural and internal design. Adequate bottom protection against underkeel torpedoes has been inhibited thus far by the combination of harbor depth restrictions on ship draft and availability of inside volume. Permanently shaped bottom protective structures can be built; they would increase the displacement of the ship and require special measures like dredging to enable harbor entry. One preliminary ship design with enhanced all-around torpedo protection, and also allowing for aircraft growth, has led to a ship designed to have about a 215,000-ton displacement, 1500-ft length, and 49-ft draft.

A compliant structure, designed to absorb the energy of an underkeel explosion, might be feasible. It would be filled with ballast water while the ship was at sea and deflated to enter harbors and drydocks. The energy-absorbing mechanism could cause the ship to grow considerably in size and displacement—about 50 ft more in beam, with about 60 ft of draft in running displacement, reducible to about 40 ft for entering harbors. This would also deny the use of current support facilities (discussed below), but it would greatly enlarge the opportunity for hangar space. In all these cases, cost

would increase proportionately to the increase in ship size and with the additional cost of the protective structures.

As an alternative, the bottom strength of a NIMITZ-class hull could be increased, at the cost of rearranging the magazine space by reducing its depth to gain more standoff from the bottom and increasing its length to recover some of the volume. Total magazine volume within the NIMITZ-class hull envelope would be reduced in the process. However, such a hull could be lengthened to accommodate the same volume without increasing the beam or draft at the cost of a slight reduction in speed (one knot or less). Further protection would require modification of the reactor mountings and some of the drive machinery, but smaller reactors (i.e., higher power density for the same power output) would be needed to avoid disturbing ship weight distribution and balance. Total feasibility and operational acceptability of these changes could be determined only from detailed design studies.

A semisubmersible design might provide significantly reduced vulnerability to damage by different mechanisms. Double- or triple-hull submarine-type hull structures would provide sturdiness against torpedoes. Minimization and splitting of the turbulent wake might make wake homing more difficult. Reactors and magazines in the hulls would make them relatively inaccessible to aerodynamic and ballistic weapons. The pylons would be thin, compartmented and have extensive structural area, so that they might be made resistant to the effects of hits in their sides. There would be more deck space for aircraft operations and for self-defense weapons, so that more hits on deck might be required to negate flight operations than might be the case for a monohull. (However, if the ship were designed for inside storage and servicing of aircraft, and if elevators were disabled, then flight operations could become more subject to interference from a hit.) Many uncertainties remain, however. These include the possibility of damaging instabilities and oscillations in the entire structure due to the effects of a large torpedo explosion between the hulls, and uncertain ability to trim the ship to maintain a level flight deck in case of asymmetrical damage.

Active Defense

Active defense of the carrier begins at long range, with the multitiered air defense and ASW at significant distances from the carrier and the battle group. Reduction in ship detectability, to some level, will be useful in

opening up the battle space for the carrier and its battle group, giving more play to its defensive aircraft screen and to the offboard defenses. However, increased speed and stealth of attacking weapons will increasingly negate that advantage.

Ship-based defenses were offloaded in modern carrier designs, and the battle force was dispersed for several reasons beyond the advantages to offensive operations: (1) as the range of defenses was extended from guns to guided missiles, capable modern systems for area defense became so large and heavy that they preempted desirable space aboard the carrier; (2) as the standoff range of the attacker increased, it was necessary to push the area defense systems (AAW and ASW) away from the carrier to cover a larger defensive perimeter; (3) housing the missile systems in an environment where aircraft could be operating when the defense systems had to be used led to the prospect of undesirable operational interference and possible fratricide; and, (4) dispersing the fleet was a means to protect its elements against multiple kills with a single nuclear weapon (after the Bikini and subsequent tests).

In the future, stealthy attackers including sea-skimming missiles, steeply diving missiles leaking through the outer defenses (including ballistic missiles able to target the ship), and torpedoes launched by submarines penetrating battle group ASW will require more active defenses to be aboard the carrier. Ballistic missile defense could be undertaken from the carrier or from accompanying ships in the battle group, depending on the tactical ballistic missile (TBM) trajectories, on detection ranges, and on required intercept altitudes and distances against different kinds of warheads. In general, as incoming threats become faster and more stealthy, or both, offboard active defense requires the defending ships to be closer to the carrier. This works against the desired dispersal of the battle group for offensive operations, and makes the battle group more vulnerable to nuclear weapons and perhaps to other weapons of mass destruction. In any case, the combination of reduced warning time and difficult intercept paths will require added defense on the carrier against the main threats, listed above.

Needed near-term improvements include:

- Phalanx Block II improvements to provide capability against agile and low observable cruise missiles.
- Increased firepower through the addition of the Rolling Airframe Missile (RAM) and improvements to NATO Seasparrow.
- Integration of self-defense weapons, ship sensors, and hard-kill/soft-kill countermeasures into a total self-defense system.

- Use of sensor data from other platforms in the battle group for early warning and cueing through installation of the Battlegroup Anti-Air Warfare Coordination (BGAAWC) system. (This extended system integration should also give attention to interoperability with other assets under command of the regional CINC that can be assigned to work with the battle group.)
- Improvements to the AEGIS system on surface combatants to provide a first-generation capability against short-range TBMs.

A more robust carrier self-defense architecture to meet the most severe future threats would include:

- An upgraded planar array, electronically scanned search and tracking radar system (the SPY-() noted earlier) having the same waveform signature as the AEGIS radar and suited to tracking cruise missiles and steeply diving targets like ATBM warheads;
- A new X-band active array radar for fast horizon search and for fire control and guidance tasks such as illuminating targets for defensive missiles with semiactive radar guidance;
- An infrared search and track system for detecting low, fast missiles, especially under emission control (EMCON) conditions;
- Improved missiles in the 400- to 600-lb weight class, with advanced propulsion and multimode guidance, able to intercept low-altitude terminal maneuvering stealthy cruise missiles and to provide self-defense against tactical ballistic missiles. These missiles would be launched from a new, small vertical launch bay designed for installation at or near the edge of the carrier;
- Improved gun systems having larger bores, farther reach, and higher muzzle velocity;
- Onboard antitorpedo defense, including means to detect, locate, and intercept incoming torpedoes;
- Evolution of the integration of ship and battle group defenses, described for the near term, above, into a modular design architecture whose features facilitate periodic change of major subsystems so that the defense system can evolve to meet changes in the threat.

None of these improvements requires extending the technological state of the art; only development is needed. The architecture can be developed as the threat develops, with early elements installed on near-term and early

mid-term carriers and later developments included in subsequent carriers and retrofitted to the existing ones. The near-term threats are sea-skimming missiles with moderately low observables; steeply diving missiles leaking through the outer defenses; and underkeel torpedoes, currently wake homers. Later threats will include missiles with smaller radar signatures and that are faster and have terminal maneuvering capability; similarly improved steep divers; underkeel torpedoes from quarters other than the stern; and tactical ballistic missiles with maneuvering warheads.

With more carrier self-defense, the function of the area defense ships, and the battle group concept of operation in protecting the carrier, must also be reviewed. Improvements should be made to the AEGIS radar for counterstealth and ATBM, and the new X-band search-and-fire control radar should be installed in the other AAW ships of the battle group. Thus the *battle group* system design would not be independent of design considerations of the carrier itself.

There is believed to be sufficient volume and weight capacity in a NIMITZ-class carrier to accept the self-defense design changes outlined above. However, ship design studies would be needed to confirm this. The impact on the carrier design itself would clearly have to be a key part of the analyses of total system defense configurations.

Unconventional Weapons for Air Defense

Several unconventional air defense technologies might potentially be brought into deployment in the mid- to long-term periods. Whether the special attributes of these technologies will be needed is speculative and depends on the evolution of the contest between the air threat and conventional gun and missile air defense weapons. The air threat growing along predictable lines (stealth, high speed, evasive maneuvers, jamming, and nonconventional payloads such as nuclear weapons, chemical weapons, or submunitions) could, in time, seriously stress conventional defensive guns and missiles. The stressing conditions are compressed battle space, need for large keepout ranges, difficult kinetic envelopes, and reduced susceptibility of the attacking weapon to damage. The technical antecedents for this threat growth exist today, but the pace at which the threat develops will be determined largely by economic and political factors, and it will probably emerge more slowly than would be possible from technical considerations alone. However, it is not improbable that unconventional technologies will be needed sooner or later in the time period being considered, either to

augment or to replace guns and missiles, and these technologies should be advanced as insurance against unfavorable developments.

Unconventional weapons, as used here, include novel weapons employing directed energy (lasers, high-power microwaves, charged particle beams); radical extrapolations of conventional weapons (hypervelocity, hit-to-kill guided projectiles, launched either by rockets or hypervelocity guns); and advanced-design nuclear weapons (compact and very low yield).

Directed-energy weapons, having negligible flyout time to target, are not stressed by target evasive maneuvers and can react very quickly to late detection engagements. Laser weapons are the most advanced variety of directed-energy weapons and could be moved into engineering development if the need were urgent. However, since the need is not urgent, a prudent course is to refine the technology in hand and to assess the prospects for superior alternatives in the future. Lasers require a clear line of sight to target. This condition is often met against low-altitude targets, and often not met with high-angle targets. The targets of greatest relevance to laser weapons are evasively maneuvering sea skimmers with non-nuclear payloads, i.e., targets that stress the kinetic envelopes of guns and missiles but do not impose a large keepout range.

High-power microwaves (HPM) are soft-kill, all-weather weapons, which are potentially complementary to but not substitutes for hard-kill weapons. Target susceptibility to HPM varies greatly with target design and with the parameters of the HPM weapon itself. Prior knowledge of the target design, such as may be available with widely proliferated target missiles, can be a major advantage in comprehensive evaluation of potential target susceptibility to determine if any modalities exist that can be exploited with compact weapon designs.

Charged particle beam weapons (CPBW) can be viewed as potential substitutes for conventional weapons. They would be hard-kill weapons with all-weather capability, and no practical means of hardening against CPBW attack has yet been conceptualized. In principle, these would make the ultimate air defense weapon. However, the feasibility of propagating lethal beams to useful combat ranges has yet to be established, and the size and weight of effective weapons based on current accelerator technology would be prohibitive. For these reasons, CPBWs are not likely to materialize as deployable weapons in the near or mid term, but if the R&D is pursued they may emerge in the long term as the weapon of choice.

Hypervelocity guided projectiles (Mach 10 and above), which can be viewed as radical extrapolations of conventional weapons, require innovation in both the launcher and the payload. They offer the critical advantage of

shortening the flyout time of the defensive weapon and reopening the engagement window that might otherwise be closed by late target detection combined with high speed and long keepout range. The projectiles must be lightweight, to keep the launch energy in reasonable bounds, and have a high ballistic coefficient to avoid excessive reduction of speed by aerodynamic drag. To meet these requirements, the projectile must have a hit-to-kill design with a terminal homer capable of functioning in the atmosphere at hypervelocity. These are technically difficult goals, but not unrealistic; the Strategic Defense Initiative Office (SDIO) is working toward a similar, if not identical, set of goals, and the Navy can draw heavily from that effort.

Two of the problems anticipated for conventional air defense missiles are (1) an increase in the miss distance, resulting from target evasive maneuvers, and (2) inadequate lethality, when the need is to achieve a warhead or payload kill (for example, if the incoming warhead were nuclear). Political and arms control issues permitting, low-yield nuclear warheads on defensive missiles could redress both of these potential deficiencies. The yield must be low enough to permit the use of these warheads in the compressed battle space expected in the future. Depending on the minimum usable range needed, the warhead design may be straightforward or very demanding. Depending on future world developments and associated policy resolutions, such warheads could be developed and perhaps inventoried against potential need, but not deployed until strategic warning shows they actually will be needed.

Key Considerations in the Active/Passive Trade-offs

As a general matter, the decision as to how far to carry passive defense as a means of protecting the ship is a major issue requiring extensive analysis and judgment. Large improvements will be costly. Some of the initial and obvious steps of signature reduction to reduce radar, IR, and acoustic signatures, and internal steps to enhance damage control, can add much for modest cost. Adding electric drive, including retractable pods to make propellers run deeper, might be more expensive than direct shafting with gear boxes, depending on the system trade-offs. Significant changes to enhance underkeel torpedo protection, requiring a larger ship, will either cause cost to rise considerably or require significant rearrangement of the internal space on a NIMITZ-class ship. Where the breakpoints occur among the different approaches to increasing survivability will require extensive research and analysis.

Figure 7.1 suggests the nature of the variation of cost with enhanced passive defense, where "vulnerability" here refers to a combination of the distance at which a signature is available for targeting and increased damage resistance measures. (Specific design and cost estimates have been deleted from the axes of the figure to keep it unclassified, although some sense of scale is provided.) The increasingly wide cost ranges as vulnerability is reduced from the NIMITZ design result from the fact that as the ship is changed more radically to reduce detectability and vulnerability, the range of uncertainty for costs increases.

The additional cost of enhanced ship self-defense as described above might increase the cost of a NIMITZ-class carrier, without size growth, by perhaps 10 to 15 percent. Figure 7.2, which shows the uncertainty range plotted in Figure 7.1 overlaid with the possible cost of the additional active defenses on a NIMITZ-class ship, indicates that at some point the costs of ship growth for passive defense and those for added active defense would be about the same.

The cost crossover between passive reduction of vulnerability and ship self-defense illustrated schematically in Figure 7.2 does not yet include total survivability, nor does it show total system cost. The cost increases for passive and active defense would be additive. Figure 7.2 suggests, however, that extreme measures to reduce ship vulnerability through passive means alone would soon pass the point of reasonable payoff, so that some combination of passive and active defense measures is preferable. Design studies and system operational effectiveness analyses are needed to determine the preferred combinations.

POWER, PROPULSION, AND ELECTRIC POWER MANAGEMENT

Nuclear Reactor Technology

Nuclear power plants for ships have demonstrated an excellent safety record and have served the Navy well. The Navy has been learning how to operate the reactors in such a way that fuel rods will last longer, meaning fewer refuelings during the lifetime of the ship. However, the technology is aging, and there have been advances that make other reactor technologies potentially more attractive for the mid- to long-term periods. In particular, reactors having the combination of inherent passive safety features as well as high power density would significantly reduce reactor volume for a given power output. As has been noted above with respect to passive survivability

FIGURE 7.1 Schematic variation of cost vs. passive protection of large CVNs.

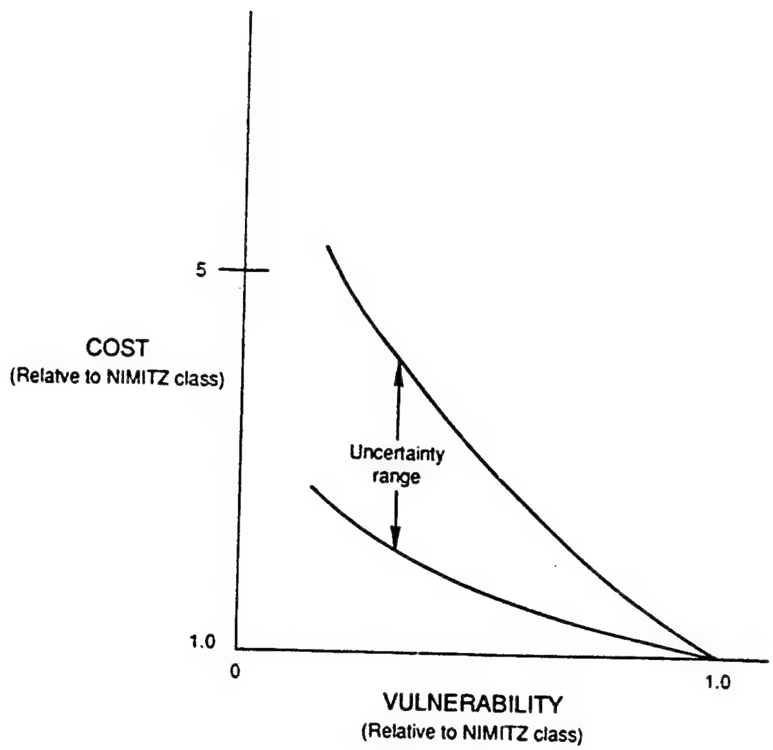
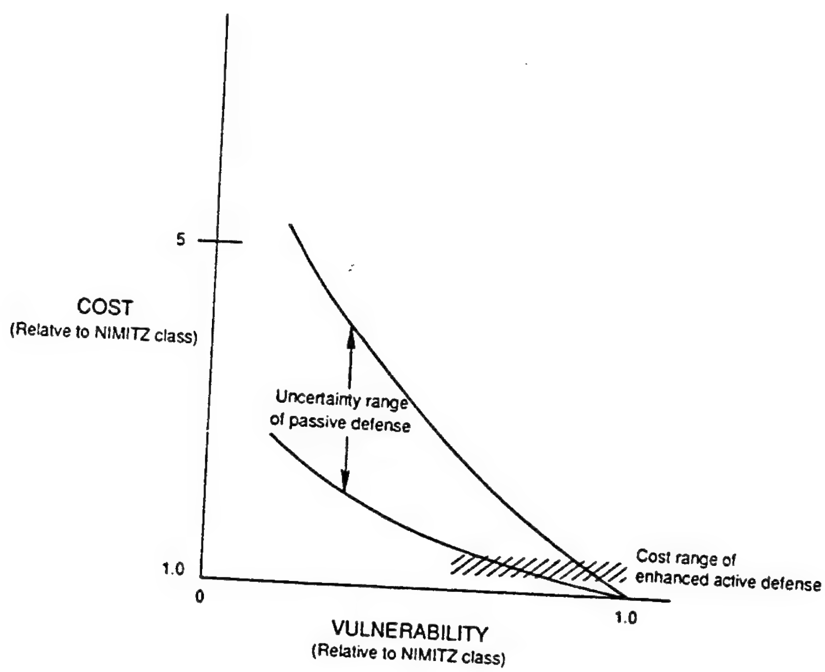


FIGURE 7.2 Schematic variation of active/passive trade-off in large CVN.



and self-defense, and as is further indicated below in connection with advanced logistic and personnel support technologies, volume aboard the carrier is at a premium. Any volume savings can be applied to making the ship more survivable against the main threats to its safety and also to enhancement of sustainability, while restraining carrier size growth and the inherent cost increase of such growth. For this reason, R&D to advance reactor technology for applications to ship designs beyond the period 2010 to 2015 can have significant payoff in carrier design, cost, and operating and combat capability, and should be pursued. The gains will have to be traded against the benefits of current technology in familiarity of operation and extended service life. The new technology must be available to create the opportunity to make the trade-off.

Energy Management

Potential benefits from increasing reliance on electric systems, if they could be achieved, have been noted in Tables 6.1 through 6.7 and in the discussion of design drivers. They include electric drive, which would enhance signature reduction and also separation of propulsion from auxiliary power, the latter making the auxiliary power much more controllable; electric catapults and arresting gear, which might save weight and volume and also contribute to signature reduction; availability of power for directed-energy weapons and electromagnetically driven, hypervelocity kinetic-energy weapons; selective application of "electrodynamic armor" when it is developed to enhance ship survivability; all-electric "yellow gear" with manufacture of hydrogen for fuel cells onboard, which would reduce ship IR signature, reduce fuel usage, and significantly ease the ability to operate with hangar decks closed to the outside for RCS reduction (all assuming the fuel cell safety problems can be solved); and significant changes in shipboard controls and operating systems.

Such advances all depend on extensive, successful R&D programs in systems for the provision and management of energy. This would include attention to ensuring that a ship has reliable power sources without fluctuations in power level and frequency, for use in ship support and defense systems and in maintenance, calibration, and repair of aircraft avionics; cryogenic electric systems and related technologies to increase the output but not the weight of large motors for propulsion; and R&D to achieve the requisite advances in power transmission, conversion, and conditioning. The major challenges are to increase the power density of the

conversion and storage media, without adding hazards to the operation of the ships and without increasing the risk of disabling damage. Such changes could lead to major design improvements in carriers of all sizes, and for this reason they are worth pursuing.

RADIO-ELECTRONIC/ACOUSTIC BATTLE MANAGEMENT AND THE INFORMATION WAR

The Navy-21 study, Implications of Advancing Technology for Naval Operations in the Twenty-First Century (National Academy Press, Washington, D.C., 1988), pointed out the importance of the "information war," in which each side attempts to gain as much information as possible about the other while denying information about itself. While the issues are important beyond carrier design per se, attention to this issue has influenced all the considerations about ship signature and defense of the carrier, discussed in previous sections. The key technologies have been listed in Tables 6.1 through 6.7.

All the possibilities for reducing electromagnetic emissions from the carrier, and for shifting some of the surveillance load from the ship to offboard assets, imply different emphases in sensor design, changes in the information processing system (shifting much of the processing and analysis that would be performed by crews aboard aircraft to terminals on shipboard) to adapt to the new kinds of available sensing and sensor vehicle technology, and a new and different communication network to ensure connectivity. More passive sensing in the IR and EM bands, LPI/LPD radar using such techniques as pseudo-noise wide-band transmission, low power transmission and very sensitive receivers, and bistatic or multistatic modes will all be necessary to preserve stealth and to pass information in new architectures suited to reducing the weight of sensor installations in aircraft and spacecraft. Similar needs in communications will encourage eliminating high-frequency (HF) transmissions from the ship except in extreme emergencies, the use of highly directional transmit-receive systems, and laser communications where feasible. Survivability needs will encourage new kinds of electronic warfare systems tailored both to carrier signature management and integrated battle group defense, including the defenses aboard the carrier. The new approach to EW will have to include attention to electronic countermeasures, counter-countermeasures, jamming, deception, and decoying in concert with reduced observability of ships and aircraft.

Such changes will apply to any carrier system design. They are under way today, supported and integrated by the establishment of the Directorate of Space and Electronic Warfare Systems and the initiation of the Navy's new COPERNICUS approach to C^3I, REABM, and combat information systems architecture by that directorate. Not all of the advances needed will be easily achievable, as experience with the Joint Tactical Information Distribution System (JTIDS), which represented a step in these directions, attests. If they are desired, their progress must be protected even under austere fiscal conditions.

UNMANNED AERIAL VEHICLES OTHER THAN HALE

Operating environments for detailed reconnaissance and target acquisition over shifting combat areas in antisurface ship warfare (ASUW) and in strike warfare to support ground forces will become increasingly dangerous. There can be significant benefit in many scenarios in avoiding manned overflight of such areas for the purpose. Remotely piloted vehicle/unmanned aerial vehicle (RPV/UAV) technology will offer the opportunity to do so. Experience to date with such aircraft suggests that their cost can be kept low by judicious design of sensor suites and data links. Recovery of the aircraft with low damage or loss rates is a significant operational problem. CTOL operation from the carrier and from amphibious warfare ships is feasible with the aircraft flown from and to the flight deck via data link by personnel on the deck. It should be possible to arrange for interleaving the operations with those of manned aircraft on a not-to-interfere basis. Such aircraft could also be operated from other battle force combatants, at the expense of more complex launch and recovery techniques and a probably higher loss rate in recovery. The aircraft would be especially valuable in direct support of landing forces.

RATIONALIZED LOGISTICS AND MANPOWER ENGINEERING

Rationalized logistics and manpower engineering are so closely interrelated that they must be treated together. Logistics and sustainability include maintenance and operation aboard the carrier, and resupply of key elements of the carrier-based combat system—especially, aviation fuel, weapons, and spare parts or subsystems. Aside from the flight crews of the carrier air wing, personnel are needed for aircraft and ship operation,

maintenance and support functions, to operate and maintain the self-defense weapon systems aboard the ship, to operate the command staffs of the carrier air wing and of the battle group or battle force, and for damage control and repair in case of accident or a weapon hit in combat.

Advances that have been made in the areas of design for ease of equipment use, computer-aided logistic support, automation and robotic aids to operations, and in classification, assignment, and training of personnel can lead to increased operational efficiencies, reflected in faster turnaround times, increased sorties, and reduced personnel aboard ship or availability of personnel for new functions without increasing the ship's complement. The advances are within the current state of the art and need only be applied for their benefits to become available.

Changes in aircraft, avionic, and C^3I system designs are changing the nature of the support required for aircraft and weapons systems. Complex electronic systems are designed for more "black box" replacement in place of repair, and automatic and built-in test equipment (ATE and BIT), although it has its own maintenance requirements, is reducing the time required for isolating and repairing faults. Maintenance manhours per flight hour are declining for the newer aircraft classes, by as much as 30 percent, even when the added burdens of aging aircraft are accounted for.

Computer-aided logistic support will improve inventory control, reduce requirements for spare parts, and enhance capability for resupply on short notice. Advanced maintenance aids will reduce maintenance time and effort by improved design of systems to be maintained and by rapid fault isolation and ergonomic design of tools and maintenance positions. Computer-based systems can significantly reduce or virtually eliminate the weight and volume taken up by paper records and instruction and service manuals by shifting them to electronic media—leading to a savings of up to 350 tons and up to 10,000 ft^3 in a "paperless" carrier. Use of composite materials, highly adherent coatings, and non-corroding alloys can reduce preservation and maintenance loads and attending manpower requirements.

There is also significant room for automation of certain critical ship functions, including especially damage control, and ship operations and repair. Because personnel aboard ship have multiple responsibilities, automation can help them considerably, but care must be taken not to reduce efficiency and chances of survival in emergencies. For example, people doing "normal" jobs may be out of position and have to move to new locations for emergency tasks. Automatic closure of routes through bulkheads could prevent this, and either reduce available crew at critical times or place people in danger or in conflict with others, or both. Also,

since damage is unpredictable, the opportunity and need to exercise human ingenuity *ad hoc* should not be lost. Automation of damage control functions should be carefully designed to help the crew in this function, not to replace them.

The improved knowledge of ship condition and ease of repair resulting from damage control enhancements will obviously also help to increase the efficiency and effectiveness of routine problem isolation and ship maintenance. Automation opportunities, such as the "instrumented ship" for ship status information and damage isolation, sensors to help guide yellow gear safely around a deck full of aircraft, and judicious application of computers and robotics will enable the ship's crew to do a more effective job with fewer people. All the improvements noted can lead to a philosophy of condition-based maintenance rather than maintenance performed according to predetermined time schedules. This, with the application of reduced-maintenance materials and structures, can be expected to reduce maintenance load and therefore manpower.

With some changes in procedures and design of functional areas like munition movement and handling systems, enhanced assembly line techniques and robotics to improve safety and reduce the time taken for functions like loading munitions can be applied to aircraft turnaround. The result will be fewer support manhours per sortie.

Many improvements are possible in the personnel area per se. Appropriate attention to selection and assignment procedures can lead to productivity gains as high as 70 percent for individual crew members in many functions. Molding the ship for habitability by using modern concepts of modular living-area architecture, food preparation, and service functions like laundry can also mean a reduction in overall personnel onboard ship and more efficient use of the remaining personnel. Techniques of embedded training through onboard team training for combat tasks and use of embedded simulation modes for practice operation of major systems can enhance and maintain crew proficiency during operational deployments. Attention to human factors in technology development can assist insertion of new technology in the carrier system without increasing manning requirements.

There would also be extensive personnel as well as operating implications if aircraft were moved off the flight deck to inside parking and support in order to reduce signature. Carrier space availability for aircraft now requires much maintenance on the flight deck. If signature reduction considerations require ship operations with temporarily fewer aircraft "buttoned up" in the hangar—i.e., no openings, normally—or designs of larger

ships allowing more aircraft to be parked and serviced inside, then the large amounts of yellow gear having to be run where the aircraft are will require a large flow of forced air through the hangar deck (or decks). This problem can be alleviated by use of all-electric yellow gear. Reducing chemical warfare (CW) vulnerability would be easier if *all* air intakes to the interior of the ship were controlled rather than having the ship partly open to natural airflow, in any case.

Changes in ship arrangements, such as locations of munitions elevators and automated loading systems, to improve turnaround procedures could also prove to be desirable for expediting replenishment. Attention to the carrier/fast combat support ship (AOE) system, treated together for such purposes, is warranted for new generations of carriers and replenishment ships. By some estimates, some simple system changes such as improving pumping rates by better matching carrier receiving stations to supply ship pumping stations, and moving ammunition elevators to a more convenient location on the carrier so that munitions could be moved to magazines more expeditiously, might halve replenishment times. Added safety from attack and reduced interference with flight operations would be gained by reducing the replenishment time.

The classified Navy Ship Operational Characteristics Study (SOCS), applied to smaller surface combatants, estimated that some 35 percent of shipboard personnel could be cut through measures such as those described above. The degree of applicability of these results to carriers is not known, but much should apply to the ship itself. Additional reduction of personnel needs should be possible through the aircraft maintenance and operational advances attainable through modern design approaches and operational techniques.

It is estimated that the total volume devoted to housing and support of each person aboard a carrier is 500 ft^3. Even a total personnel savings of 20 percent on a NIMITZ-class carrier would make available about 650,000 ft^3 of volume. All the volume would not be recoverable, but careful design might make available a significant fraction of it. This available volume could lead to flexibilities in design that encompass but go beyond the issues of personnel alone. The added volume could be devoted to space for more active defense, for added torpedo protection, or for more aviation fuel and magazine space.

Thus the potential personnel savings and operational efficiencies achievable from application of modern personnel and logistic engineering can be translated into increased ship sustainability and survivability, as well as reduced O&S costs. Achieving these gains will require attention from

the top levels of the Navy where carrier system characteristics are specified and their implementation supervised, since none of the designers, builders, program managers, or commanders at the ship and aircraft subsystem and system levels is responsible for the overall level of personnel on the ship or the cost and effectiveness implications of personnel-related decisions that they may make.

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CARRIER SYSTEM OPTIONS

Careful consideration of the carrier design drivers and of the possibilities for resolving the problems they pose points to four basic alternatives for future aircraft carriers and carrier systems, with many possible variations of the four. Obviously, since the carriers considered here will be acquired over a considerable period of time (40 years), a fleet will be built having more than one ship design, so that the Navy can take continual advantage of advancing technology.

The basic concepts that were examined are enumerated immediately below and then are discussed. Clearly, since one approach has already been recommended earlier in this report, these options have already been evaluated in light of current needs and conditions. The options are presented and discussed, however, (1) to show the range of possibilities that was considered in arriving at the recommendations, (2) to indicate the possibilities that may be of interest and available for some time in the future when world conditions and the needs for naval power will surely change, and (3) to establish the basis for the recommended carrier-oriented R&D program. The options are the following:

1. *An advanced NIMITZ-type ship, within the NIMITZ-size envelope.* Such a ship would be changed to the extent feasible to meet some of the most severe threats and engineering problems foreseen and to capitalize on some of the most important of the technological opportunities in the offing, to the extent permitted by the size of the ship.

2. *A new, large monohull.* This ship would offer more scope for change, including potential growth in size and weight of the aircraft of the carrier air wing to achieve improved range and payload, and changed onboard system characteristics to provide more opportunity to strengthen passive and active defense, and more opportunity to capitalize on some major technological advances such as electric drive and advanced, electrically based weapons, along with the advances possible in the NIMITZ-class ship. Torpedo protection and larger and heavier aircraft would cause this ship to be larger than one in the NIMITZ class. The smallest size might be about 105,000 tons and 100 ft longer than a NIMITZ-class ship, and a much larger

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one that incorporates all the survivability changes contemplated might reach a displacement of 215,000 tons and 1500 ft in length.

3. *A large semisubmersible ship.* Designed to lower signatures and to enhance damage resistance, this ship would have a rectangular flight deck of approximately the dimensions of the NIMITZ flight deck, configured to operate with all aircraft in the hangar decks except when being launched or recovered. It would be ballasted to run with the propellers on the submarine-like hulls at about a 125-ft depth but would be able to reduce ballast to draw about 40 ft to enter harbors. This ship would displace about 325,000 tons, empty, and about 660,000 tons with ballast and the hulls at running depth.

The above three alternatives would be able to operate a carrier air wing of 85 to 90 aircraft, having the multi-capability mix of today's air wing, under different conditions of in-hangar or on-flight-deck parking, servicing and operation, self-defense, and offboard support for the different ships.

4. *A carrier of LHA/LHD[2] size or one somewhat larger (e.g., 40,000 to 50,000 tons).* It would be designed to operate an air wing of about 30 new STOVL fighter/light attack aircraft in the F/A-18 weight class with supersonic cruise capability, or smaller numbers of aircraft in a mix of the STOVL fighter and high-performance rotorcraft for supporting missions. It would not have catapult and arresting gear. The ship would be planned for use in a complementary air defense and ASW role with the large carriers, in support of amphibious operations, or by itself in less demanding environments. *The value and viability of such a carrier would be contingent on development of the new aircraft.*

Each of the four alternatives offers various advantages in ship design and operation. Each differs significantly from the others in the opportunities it poses for accommodating to the design drivers and the problems they raise. Each has its own costs, problems, and uncertainties that in the aggregate will pose serious decision problems for Navy force and budget planners. Each would have a different impact on the design of the total carrier system. These factors are reviewed in the following discussion.

[2]The largest class of amphibious assault ships.

ADVANCED NIMITZ-TYPE CARRIER

Typical characteristics and improvements could include, among others:

- Current-type operations, with aircraft stored and maintained, to the extent feasible, on the flight deck. It could accommodate aircraft of the size that had been planned for the A-12: however, potential growth of ATS aircraft or other follow-ons to the aircraft now performing the ATS missions in order to achieve greater range and payload performance and more advanced, counterstealth sensors would lead to a very tight fit. This could enforce more reliance on offboard surveillance and targeting assets.
- Modern, late-cavitating propellers, steps to quiet machinery, and steps to reduce RCS and IR signatures to the extent feasible within the basic design.
- Planar array, electronically scanned radars (as described in the discussion of ship survivability and defense, Chapter 7), replacing the current radars, and LPI/LPD communication systems with low-observable planar array antennas. These changes, together with other signature management steps, would require complete redesign of the island, and so would constitute a major change in the ship configuration.
- Enhanced self-defense, including advanced missiles of SPARROW size in appropriately designed VLS bays, and active torpedo defense—all to the extent permitted by weight and space constraints.
- Selective application of upgraded armor.
- Enhanced damage control, including widespread instrumentation, computerized damage diagnostics, more fire and smoke retardant materials, and automation where it can be effective in helping the crew with damage control.
- Extensive internal redesign to improve ship and aircraft operational and maintenance efficiency and reduce crew size.
- Possibly, significantly greater torpedo protection, or aviation fuel and magazine capacity, if the maximum volume that might be gained through personnel savings were used for one of those purposes.
- For the late mid-term and long-term designs, advanced reactors if these prove to be preferable, and advanced power transmission and management systems, associated with electric catapults and arresting gear and possibly with advanced defensive systems.

The extensive changes would greatly improve the efficiency and effectiveness of the carrier. It would still fit in the existing drydock and port facilities. However, it would also still include some major vulnerabilities. Among them would be continued, relative ease of targeting by threat systems, although the reductions in signature would ease the demands on EW protection and on use of cover and deception such as decoying. Major vulnerability to underkeel torpedos that might penetrate the active torpedo defense would remain, unless enough volume for added underkeel torpedo protection could be recovered and used through the other changes noted in ship design.

The least-cost option among all those available with the offensive strike capability and the defensive air power of a NIMITZ-class carrier would be simply to purchase NIMITZ-class follow-on ships indefinitely. This would carry many of the survivability problems of the NIMITZ into the indefinite future, and it would deny to the ship and the carrier system the benefits of advancing technology, while potential threats would probably continue to improve as described earlier.

The improvements outlined above could add initial cost of up to about 10 to 15 percent to this option, although they would save in downstream costs throughout the ship's service life. Such improvements would enable the ship to keep up in some significant degree with changes in the future operating environment.

NEW LARGE MONOHULL

This option could include all the improvements outlined above for an advanced NIMITZ-class design, with the opportunity for further improvement in several directions:

- Addition of from 100 ft to about 400 ft to the flight deck, enabling the ship to operate the largest aircraft currently being contemplated (up to 125,000 lb TOGW). The addition of 100 ft to a NIMITZ-class ship would entail growth in other dimensions if one wanted to maintain the same prismatic factor, which is very favorable for hydrodynamic design and ship speed. If a small (one knot or less) reduction in speed is acceptable, "stretching" the NIMITZ hull by, say, 125 ft, would allow changes in the magazine to provide some measure of passive protection against underkeel torpedoes and would also accommodate the heavier aircraft in the offing. A ship

at the other extreme (i.e., 400 ft) would grow significantly in all dimensions—the overall beam would be about 300 to 350 ft and the draft would be nearly 50 ft if underkeel torpedo protection were provided with a rigid bottom.

- Addition of underkeel torpedo protection. This would be built into the basic structure of the ship, at least in part, and might be augmented by compliant bottom protection if necessary to absorb the energy of a large torpedo explosion. In the latter case the ship would draw up to 60 ft while at sea, but it might be found feasible to reduce this to about 40 ft by pumping ballast out of a flexible, collapsible bottom prior to entering harbors. (The "stretched NIMITZ" alone would not draw more water.)
- Greater opportunity for signature reduction accompanying the hull redesign, thereby increasing the difficulty of targeting the ship and increasing the opportunity for effective cover and deception by electronic countermeasures (ECM), chaff, and decoying.
- Opportunity for much more hangar deck space resulting from added ship size and perhaps from personnel efficiency gains, so that the ship could operate with an 80+ percent-sized air wing with no parking, turnaround, or maintenance activity on the flight deck, *or* for sharing the volume gains with other alternative improvements noted immediately below.
- Much enhanced self-defense relative to what could be accomplished within the NIMITZ-class envelope.
- Significantly increased fuel and magazine volume to increase sustainability in combat, depending on the actual ship size and on whether volume saved from other applications were used for these purposes.
- Opportunity for podded electric drive, when available.

These additional gains in capability above those of the improved NIMITZ would require a ship that might vary from about 125,000 tons to about 215,000 tons. Home harbors might have to be dredged to handle the ship, especially in a rigid bottom configuration. The hull designs contemplated would mean that the ship could not use available drydock facilities. The additional cost of the ship alone would be 10 to 100 percent greater than that of a NIMITZ, depending on the size and the extent of the changes incorporated. The cost of new port facilities for the new ship class would have to be borne; this might come to about $2.5 billion to $3 billion for facilities on both coasts (less for the "stretched NIMITZ" since a graving

dock exists in which such a ship could be built). If the cost of new drydocks for ship repair were to be saved, other means for working around the facilities problem (discussed below) would have to be adopted, at some unknown cost.

LARGE SEMISUBMERSIBLE

The attraction of this ship is that it could offer the lowest detectability against targeting and, depending on the resolution of some structural unknowns, possibly the greatest structural integrity against major damage. (It could probably still be targeted from outside visual range, however.) The ship would be about 1100 ft long and would have a beam of 250 ft for the rectangular flight deck. If the ship were a SWATH, the underwater beam would be larger because of the overhang of the 125-ft-diameter hulls from the profile of the pylons (a "golf-club" configuration could be used to stay within the overall beam, but this would not be as stable or as efficient hydrodynamically). The ship would draw about 185 ft while under ballast at sea with the propellers at a depth of 125 ft, but it might be designed to draw as little as 40 ft without ballast, to enter port. (Its height might then interfere with bridges in some ports.) The ship would displace about 325,000 tons empty and about 660,000 tons in ballasted configuration. The reactors and magazines would be in the hulls, where they would be less accessible to attack by airborne weapons, and hangar deck space would permit the full air wing to be housed, turned around, and maintained inside the ship, with advantages in signature reduction and controlled conditions for the crew in severe weather. It would use submarine technology for quieting, and double- or triple-hull submarine-type construction for damage resistance. Its speed would not be as great as that of the NIMITZ (25 knots vice 30+ knots, with four times as much installed power). However, speed would affect only deployment time; wind-over-deck requirements could be reduced significantly by use of a skijump, and deck parking space would not be needed.

This ship would be large enough to accommodate operations by the largest aircraft being contemplated, especially with a skijump and catapults for takeoff and longer runouts for the arresting gear, without extensive wind-over-deck requirements. The rectangular deck would have ample space for added self-defense that the passive/active defense trade-offs might suggest for a ship of its potentially low detectability. There could also be space and

weight capacity for a significant number of offensive long-range missiles for defense suppression to support strike warfare. The rectangular flight deck, potentially configured as two parallel runways, would offer great flexibility for simultaneous launch and recovery operations.

All of the other improvements for efficiency and effectiveness that have been sketched above for the large monohulls would be available to this ship. Total redesign of the use of space on board would clearly be required, however. The ship would also need new building and port facilities. A mode for working on the ship in water and at dockside once it is in service, without the usual drydock facilities, could be devised to minimize the new fixed facilities that would have to be built.

A rough estimate of cost for this ship, based on a synthesis of submarine costs for the hulls and monohull carrier costs for the superstructure, leads to an estimate of about three times the cost of a NIMITZ-class carrier. However, a ship of this kind represents a very long extrapolation from current experience with semisubmersibles—currently, 3500 tons in operation and 5000 tons in design. Experience suggests that many "unknown unknowns" would be encountered in the course of design, construction, and operation, so that an increase to a factor of four times the NIMITZ class cost might be an outer limit.

The benefit gained for the added cost would be the potentially great increases in survivability and firepower. These increases in carrier capability could offset the carrier costs by avoiding the costs of other battle force combatants that might not be needed to protect the ship. These trade-offs would have to be explored in depth through R&D, model tests, and design studies, including analyses and simulation of the entire battle group in high-intensity operations.

LHA/LHD-SIZED CARRIER

The flexibility advantages and mission opportunities of this carrier in complementing the force of large carriers were noted above, in connection with the technological attraction of powered lift aircraft. Considered *ab initio*, this ship can be a monohull or semisubmersible. The alternatives are considered to be in the same class because of their size, the needed companion design of a powered lift air complement, and other attributes such as the need for heavy reliance on offboard protection and information sources for their combat operations.

The semisubmersible would offer sea-keeping in heavy seas about as good as that of the NIMITZ-class carrier, extending its operational capability into more severe weather conditions—a major concern with respect to smaller carriers. It would also offer improved survivability features for the same reasons that the large semisubmersible would, but not to the same extent. However, calculations show that for the same flight deck size the semisubmersible would have to be a considerably heavier ship—by as much as a factor of two. All of the unknowns and uncertainties of the larger semisubmersible design would apply to this one as well, since the needed extrapolation from actual experience would still be large. Thus, further review of the smaller-carrier option has centered on the monohull design.

Passive torpedo protection for this class of ship would be infeasible against torpedoes that can seriously threaten a NIMITZ-class carrier, although some protection against smaller torpedoes would be feasible. Many of the other opportunities for improving ship survivability, such as the more liberal use of armor and instrumenting the ship to enable more responsive maintenance and damage control, would be applicable to this class of ship, as would many of the weapon technology advances described above.

All of the opportunities for improving the efficiency and operability of the carrier and its air wing would also be available for this ship, but the application might have to be more measured because of the ship's smaller size. Less volume for the magazine and aviation fuel would increase the need for more frequent replenishment. There would be insufficient space to perform intermediate maintenance aboard this ship. Some of the improvements, such as electric drive, could be available sooner, based on the lesser extrapolation that would be needed from battle force combatants' electric drive currently in development.

A monohull ship of this size would not stress the available facilities. The cost of the ship would be less than the cost of the larger ships described above, since for ships of similar design costs vary roughly according to weight, but the cost would be larger per ton because many design efficiencies available to larger ships would have to be foregone. A rough estimate analogous to the others made (and based in part on the studies performed during the CVN-CVV discussions of the late 1970s) suggests that a 50,000-ton carrier might cost about 55 to 65 percent as much as a NIMITZ-class (95,000-ton) ship.

SYSTEM IMPLICATIONS OF THE OPTIONS

The overall system implications of the options have been noted throughout the discussion. They are reviewed in expanded form here.

Advancing technology will make available many improvements in carrier design that should be incorporated because they will improve survivability, improve combat power, reduce personnel requirements, and enhance operating efficiency and sustainability. Although the Soviet threat has subsided at least for the time, the next-generation carrier and those of succeeding generations will have to contend with potential opposition, including many countries that even now are acquiring advanced technical and combat capabilities that can stress the carrier system to its limits.

The implications for the carrier system are, therefore, that it will not only be *desirable* to be changed to achieve the potential efficiency improvements, but that it will also *have to* be changed to meet increasingly capable opposition. The changes will not be in the directions that the earlier Soviet threat demanded, but they will have to include within their pattern the ability to meet a renewed threat from that quarter should it arise. Conversely, many of the changes would be beneficial for operational and economic reasons even if the Soviet threat had remained.

Many changes in the anticipated operating environment and responses to those changes will press for carrier growth. Future carrier designs will face continuing tensions between the pressures for the ship to grow and compromises to restrain growth.

The diffusion of potential threats against the carrier to more areas of the world, and the dangers of operating close to hostile shores against technically capable opponents, will require the carrier system to be capable of longer-range strike operations than current aircraft designs permit. Strike operations will use more standoff weapons, requiring a significantly expanded effort to create targeting maps, and more guided weapons will be used even for close-in attacks. Recent design experience with the abortive A-12 and with the canceled or deferred NATF suggests that the larger combat aircraft implied by the greater operating ranges would still fit within the NIMITZ design envelope.

Operations in littoral areas that open the carrier to attacks by land-based tactical aircraft launching stealthy antiship missiles, and spreading of modern undersea warfare capability to many Third World countries, will require long-range surveillance, EW and ASW support, and assistance for counter-action against such threats. The support and surveillance aircraft can become large and heavy enough to cause the carrier to grow. The

carrier design can go only a certain distance to meet this problem; the support will have to be provided by a mix of onboard and offboard assets, the exact mix to be determined by the size of the carrier and the capability of the aircraft involved.

The criticality of the advanced tactical support (ATS) function as a driver of carrier size depends on where the problem is partitioned and how the support burden is divided. It is becoming clear that the NAVY can no longer rely wholly on assets within the ships of the battle group alone to perform the entire support task. As happens today, the carrier will be able to carry out some significant set of problems by itself, and then the battle group will have to be augmented by outside assets for the purpose. The mix in the future will be different from what it has been to date. The possibilities have been reviewed in "Trends in Aircraft" in Chapter 7.

Such a new tactical support system configuration would not only be more effective in many situations the future carrier might encounter outside potential conflicts with the Soviet Union, but it would also be well designed to deal with a resurgent Soviet threat should that appear. This would be a reasonably safe position against future uncertainty, and there is time to build it. It would also avoid the problem of having an ATS aircraft or set of aircraft that would have to be tailored to two different sizes of ship coexisting for 25 to 40 years.

The means of providing offboard support will be effective against conventional threats, but they will not easily solve the problem of targeting stealthy attack missiles; that will have to be done from the carrier or from other battle group ships operating very close to the carrier, until the state of the art in sensing advances well beyond where it is today. Reducing the dispersal of the battle group will increase battle group vulnerability to nuclear weapons, which may appear in Third World arsenals in addition to those of Soviet forces.

Increasing threats against the carrier will lead to major design changes in the ship itself. Passive defense changes include reduced and modified signatures and internal changes to reduce the effects of damage and to enhance the ability of the ship to sustain hits with less damage. Added active defenses, including more missile and close-in gun or (ultimately) directed-energy weapons and hypervelocity kinetic-energy weapons installations, might require carrier growth if they are elaborate enough. Passive damage limitation against the underkeel torpedo threat, which can be spread by the Soviet Union whether or not they pose a direct threat to the carrier over its lifetime, would cause the carrier to grow the most.

Growth in the size of the ship should not be viewed as undesirable, however, if the cost can be accepted. A larger carrier can be made more survivable. It could operate larger aircraft that would be more capable and would give the system more striking power at longer range. A larger carrier could also allow for onboard installation of long-range missiles to suppress defenses against the carrier's strike aircraft, enhancing their strike capability further. If this is not accomplished by missiles from the carrier, ammunition aboard the other battle force combatants and strike sorties from the carrier must continue to be devoted to the purpose. If it *is* done from the carrier, the other battle force combatants may become less critical to defense of the carrier system, and they may be devoted more to offensive missions.

Passive defense against large underkeel torpedoes will be foregone if the ship is not allowed to grow, unless ship design efficiencies can free enough volume to accommodate such defense. This could mean reducing the size of the magazine and of the air wing; the loss might be made up by more use of guided weapons, but a shorter period of sustained combat power (fewer warheads delivered over a shorter time against large target sets) would probably result even in that case. If the resulting survivability/strike balance proves undesirable and the added risk of losing the ship is accepted, there will be a number of ways to avoid pressures toward growth of the carrier.

Shifting more of the surveillance burden to offboard assets, already discussed, is one. Except where engagement envelopes allow no choice but to use self-defense weapons aboard the carrier, the carrier can participate in cooperative engagement with other ships of the battle group. The concept can be extended to encompass cooperation with appropriate forces of other armed services under the command of a regional CINC, as is done today. Interoperability with those forces would have to be assured in the design of the carrier system and the other forces.

Aside from the increase in cost attending size growth and the construction of the lead ship in a new class, a major concern if ship size grows would be the concomitant need for new port facilities.

There are five private and seven government-owned drydocks distributed on both coasts that can house NIMITZ-class carriers for repair and overhaul, with two on each coast certified for nuclear carriers. There is only one shipyard, in Newport News, Virginia, with a graving dock to build such ships. The main need for drydocks, beyond ship construction facilities, is for painting the wetted surface, removing or installing propeller shafts, working on the water-intake manifolds, aligning the catapult, and damage repair. The NIMITZ-class carriers press drydock facilities to the limit, since the ships in their current configuration barely fit. Side and sill clearances are

very small, there are upper deck overhangs in some drydocks, sponsons must be removed to enter some, and draft also must be reduced from 37 to 33 ft to enter some drydocks. If the carrier grows larger, or if its shape is changed drastically (as for a semisubmersible, or for podded propellers for electric drive far outboard and deeper than the main hull of a monohull), it will not fit.

There are ways to work around the lack of a drydock if a new carrier cannot fit. This includes working at dockside, and/or building watertight cofferdams around the parts of the ship that need work in dry conditions. It may be possible to develop ship cleaning and painting machines and materials that can be used under wet conditions. All this would amount to building a new infrastructure if carrier size grows or its design changes radically.

Building a new infrastructure can include building new, larger drydocks. Two would be needed on each coast, at a total estimated cost of about $2.6 billion. One graving dock would be needed to build the first larger carrier designed for the new aircraft starting in about 2010. Additional facilities would be needed in time to start the next ship of the new class, perhaps within 3 years of the first one, and for initial overhaul of the lead ship 7 years after its commissioning. Thus, the outlay for new facilities could be limited to under $100 million per year until acquisition of the first of the new carriers, but it may have to rise after that.

Another approach to solving the multiple problems of increased vulnerability and pressure to grow is to change the carrier design completely by taking advantage of the passive protection possibilities of semisubmersible ships. This change would also provide operational flexibilities in aircraft design and operations and in ship self-defense that would not be available from monohull designs. Much less active defense might be required, leading to savings in the battle group that would offset the higher cost of the ship. The foreseeable gains would come at the expense of undertaking a high-risk design for which there is little basis in experience. Changed modes of carrier operation, affected by speed, operational depth, and handling in harbors, would have to be devised if such a ship were built.

All the changes in ship design that move toward larger or radically changed ships will entail increased cost for the ships and for shore facilities to build and maintain them. Design changes to make a particular ship configuration more efficient and to increase its damage resistance could add to or reduce costs, in some combination that will not be known until a new design is undertaken. This will be true for ships that do not grow in size as well. Many of the cost increases will be offset by reduced life-cycle costs,

requiring the budgeting and planning system to exchange near- for far-term savings. Other cost increases will simply be necessary to ensure that the ships can remain survivable and effective throughout their lifetimes.

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LARGE SEA-BASED PLATFORMS—A SPECIAL CASE

In asking the Secretary of the Navy to have this study performed, Congress also expressed interest in an exploration of the possibilities for building floating platforms from which all manner of aircraft, rather than those configured for current types of aircraft carriers, could operate.

A number of possibilities have been examined in the past,[1] and they can furnish data and a conceptual basis for the current application. Two basic concepts have been considered. One amounts to a floating island that would create the equivalent of a tactical airbase offshore from the area where it is established. The other would amount to a very large aircraft carrier, beyond any of those considered thus far in this study. The first would be an essentially fixed base, relocatable with considerable effort, while the second would provide a more mobile base, without the agility of a carrier. The two concepts are reviewed briefly.

FLOATING ISLAND

To meet mission requirements significantly beyond those of a current aircraft carrier, the floating island would have to be big enough to allow takeoff and landing of all kinds of aircraft, ranging from fighters not configured for catapulted takeoffs and arrested landings to tactical transport aircraft. Benchmarks may be provided by the damaged-runway requirements for land-based tactical aircraft. Typically, 2000-ft-minimum field lengths are specified for assisted or lightweight takeoff and lightly stressed arrested landing for land-based tactical fighter aircraft. C-130 tactical transport aircraft can operate from similar field lengths. Larger aircraft like the C-17,

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[1]References: "Floating Stable Platforms, Concepts, and U.S. Activities," by Hightower, J.D., Rona, T.P., and Talkington, H.R., Naval Ocean Systems Command, 1989; "Floating Ocean Platform," memorandum by Kostoff, R., Office of Naval Research, for NSB, Dec. 1990; "Advanced Offshore Oil Platforms," by Ellers, F.S., *Scientific American*, 246, No. 4, April 1982; "Study of Large Floating Bases," by Bechtel Corp; "Study of Offshore Tactical Air Base," by BDM Corp; "Mobile Offshore Bases," by Hickey, E.I., Dailey, J.E., Nolan, C.E., and Gaul, R.D., presented at First International Workshop on Very Large Floating Structures, sponsored by University of Hawaii with National Science Foundation funding, Honolulu, April 1991.

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or heavily loaded tactical fighter and attack aircraft, would need runways on the order of 3000 to 5000 ft. In addition, a flat surface is needed for taxiways and on which to build housing and aircraft support facilities.

Available technology for floating platforms allows relatively inexpensive construction in modules based on vertically floating, hollow steel, aluminum, or concrete columns tied together by a platform on top, and joined all together to make a rigid surface from which aircraft could land and take off. While much of the platform could be simple runway and taxiway, some significant part of it would have to contain facilities to house and service aircraft, for crew quarters and working space, command staffs and aircrews, and all appropriate shop, power plant and fuel and ammunition storage facilities, as well as platform self-defense.

Cost estimates made by various firms for offshore airfields that would include hangar, servicing, and shop space suggest an estimated cost of $4 billion for an airfield with dimensions of 9000 by 900 ft. However, although the technology for a single module represents a modest extrapolation from known technology, multimodule construction and assembly at sea have not yet been demonstrated. The costs of defending the base and other specifically military aspects of the floating airbase's capability would have to be added. Consideration of such factors leads to the coarse estimate that the base could cost as much as $8 billion, completed for a military mission.

The platform would be very heavy. Deep-ocean oil platforms can weigh between 0.5 million and 1 million tons, and rough estimates for a platform of modular construction such as that described above suggest that its weight could come to 5 million tons. There would be problems in tying the platforms together so that they could withstand waves, winds, and ocean currents; keeping them level and rigid so that aircraft could land and take off; achieving anchoring or dynamic station keeping against very large current and wind drag; and enabling acceleration, deceleration, and control for major position shift. While most of the technology is known, the problems of assembling such a large structure, while they have been examined in connection with providing offshore commercial airfields in such places as Tokyo harbor, would be essentially new in practice.

It has been estimated in some studies that sections could be moved by tugs, much as large oil platforms are towed to locations in the North Sea. However, moving the entire structure against wind and ocean current loads would probably present a problem of a different order. One estimate suggests movement at 3 to 4 knots, with enough power in the tugs, but the problems of anchoring and moving such a large platform are beyond

experience. Even if it could be moved without disassembly, it could not pass many narrow or shallow straits, requiring much more time than even the slow speed suggests. From these considerations, it appears that moving the "island" could amount to disassembling it and essentially rebuilding it in another place, at some unknown cost.

SEMISUBMERSIBLE SHIP

A mobile alternative to the floating platform technology described above might be provided by a very large semisubmersible ship, like a SWATH, on the order of 2000 ft long. With a skijump at the leading edge of the flight deck and arresting gear having a long runout, this ship would be able to accommodate any tactical aircraft designed to operate from a runway with bomb holes, and C-130-type transport aircraft (assuming any superstructure could be appropriately designed). Incorporation of catapults would allow carrier-capable aircraft to operate at any foreseeable gross weight without the need for wind over deck, and there would be ample room for aircraft weight growth of the magnitudes discussed earlier. An additional advantage of such a ship would be its mobility; with 600,000 to 700,000 installed horsepower, the ship might be able to move at 20 knots on its own.

This ship might cost about 12 to 16 times as much as a NIMITZ-class carrier. This guess is based on the estimate (given earlier) that a semisubmersible with an 1100-ft flight deck could cost about three to four times as much as a NIMITZ, and on the assumption that although it would grow to twice the size of the latter semisubmersible, the weight of the ~2000-ft-long ship would change roughly as the square of the linear dimension rather than as the cube since the ship would be mainly hollow (thus, a factor of four in doubling the size of a semisubmersible ship that was, earlier, estimated to cost three to four times the cost of a NIMITZ-class ship; this leads to a cost for the 2000-ft semisubmersible of 12 to 16 times the cost of a NIMITZ-class ship). This would place the cost of this ship at roughly $40 billion to $55 billion. The difference between this cost and the estimated cost of the floating platform would be the price paid for mobility.

COMMENTARY

Missions and operating conditions for platforms such as those described here have yet to be defined clearly. If either platform were used very far off

a hostile shore, tactical aircraft range could become a problem. If they were used in close, they would not have the mobility advantages of a carrier but they would have most of the physical and many of the political vulnerabilities of a land base.

This first-order examination led to the judgment that the large sea-based platform concept is different in kind from the aircraft carrier concept and would serve different functions. The ship version of a large floating platform can be ruled out on the basis of cost. (This could change if research on the large semisubmersible carrier considered as a NIMITZ-class replacement suggests engineering feasibility and potential costs much lower than those estimated here.) The large floating base would be akin to having a fixed, quasi-permanent overseas tactical airbase, moved offshore because it is not wanted or cannot be accommodated onshore. The carrier is designed to carry out missions requiring mobility and the ability to appear and operate in particular geographic areas and then to shift to others on short notice. The two concepts are not alternatives for each other, and each needs evaluation in its own frame of reference.

Examinations of the "floating island" concept beyond this "zero'th order" look would first have to consider the missions that would justify such platforms, as compared with more conventional aircraft carrier concepts. They would then have to review platform technology; construction and assembly, including single platforms and multi-platform assemblies; stabilization, seakeeping, and maneuvering at sea; load-bearing and smoothness; mobility; cost; vulnerability and protection; and operational suitability. Based on the prior work that has been reviewed (see Volume II), such further examination would be warranted if a mission structure for such a base were to be defined.

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CARRIER-SYSTEM RESEARCH AND DEVELOPMENT

The many areas of ongoing technology development listed in Tables 6.1 through 6.7 offer the potential for the capabilities needed for and/or useful in the design of future carriers and parts of the carrier system. Some of the technology advances are either close to fruition or ready for current exploitation. R&D for others is in train and in the normal course of program development will lead to the technologies listed. Many of the latter deal with aircraft, weapon, and REABM system technology that is being pursued independently of ship development.

Some of the areas of ship and ship system development are also under way in existing programs, while others may need significantly more emphasis to ensure their timely availability for application to the next generations of aircraft carriers. Some of the latter, such as ship power conditioning or directed-energy weapons and hypervelocity kinetic-energy weapons ship self-defense systems, will not develop without explicit decision and R&D emphasis.

While there are R&D programs for weapons, aircraft, and smaller ships such as battle force combatants, there is no R&D program explicitly designed to advance the carrier or the integration of all the component systems into the carrier system as a whole. Many of the advances in other areas can have the effect of advancing the carrier and the carrier system, but adaptations become necessary during carrier design and construction. A program of R&D explicitly designed to advance the carrier and the overall carrier system would include many of the ongoing R&D programs, but it would give them more or different emphasis. In addition, some R&D is unlikely to be pursued unless explicitly undertaken for the carrier system.

In particular, management attention is needed to the *process* of ensuring that the R&D results are brought together into the carrier system in a planned and orderly way, and that appropriate attention is given, within the Navy R&D program, to carrier-specific needs and their integration into the carrier system as a whole. This attention would focus on designing carrier systems to accept change; ensuring continual technology insertion at appropriate stages of carrier modification or new design; simulating of potential technologies in appropriate environments to ensure their feasibility and workability for carrier application; prototyping of carrier-specific subsystems before development when size permits; and paying specific

attention to enhancing the connections among user, developer, and technologist.

The following list highlights the research and development *that should be emphasized* to advance the carrier system and to make accessible some of the carrier design options that are not available today. The time periods are indicated when achievement of significant results can be expected, as are judgments as to level of risk associated with development of the technologies. All of the efforts listed, if pursued to completion, would be expected to have high payoff for carrier capability.

As a general matter, although there will be exceptions, the longer it takes to achieve a capability in the operating fleet, the higher the technical risk involved in implementing the capability in the carrier. This is because risk is linked to the state of the art and of practice in the technology. Low-risk activities are those based on technology that has been implemented in the field at some point, requiring only the time and resources for application and integration in some current context. Medium-risk efforts are those for which the basic phenomena are reasonably well understood, and which may have been the subjects of successful laboratory experimentation, but which have yet to be applied to an operating system. High-risk endeavors are those for which the concepts and early theory and experimentation may exist, but for which much of the phenomenology remains to be described and implemented in hardware or software. The technical risk involved in trying to bring them to successful application is therefore high, because unknown or unexpected hurdles can prove highly expensive or even present insurmountable difficulties. It follows that higher risk entails greater expense, within the characteristic cost level of subsystems and systems under consideration, if only because it takes longer to achieve success. Also, as will become apparen depending on the capability it can take more or less time to bring a capability to fruition, regardless of the level of risk.

1. Aircraft Systems

- Range extension for conventional aircraft (30 to 50 percent extension as goals), while incorporating high-lift aerodynamics and thrust controls for low stalling speed and controllability in launch and recovery (near to mid term; low risk).
- Structural materials supporting low observability (LO) designs able to withstand carrier environment (near to mid term; medium risk).

- High-performance rotorcraft concepts for ASW, tanker, COD, and rescue (near to mid term); with modular equipment to convert a standard platform to the various missions economically (long term; low to medium risk, depending on the implementation).
- Improved night/bad-weather landing systems and other operational enhancements for sustaining operating rates around the clock.
- STOVL supercruise fighter/attack aircraft technology and prototype development (mid term; medium risk).
- Lightweight counterstealth aircraft radar systems for carrier-based AEW aircraft (mid term; high risk).
- Unmanned aircraft surveillance systems, especially HALE, with spacecraft reliability, very long endurance (days or weeks with midair refueling), air-to-air refuelable from the carrier (designed for over-the-horizon surveillance, AEW, C^3I link, EW, and related missions or parts of missions—mid to long term; medium risk).

2. Passive Carrier Survivability (Supports current and near- to mid-term ships, depending on extent of change required in ship design.)

- All areas of ship, aircraft, and weapon system signature management in the radar, acoustic, and IR media. (Electromagnetic emission signature management will accompany weapon system changes; some wake reduction will accompany ship design changes listed; low to medium risk.)
- Damage isolation and control throughout the ship, including improved ability to deal rapidly with fires on the flight deck (low risk).
- "Instrumenting" the ship, and advanced internal communication systems, to support damage control measures; also contributes to more efficient condition-based ship maintenance (medium risk).
- Passive torpedo protection, including especially protection against underkeel torpedoes (low to high risk, depending on implementation).
- Advanced armor for selective protection of critical ship areas (medium risk).

3. Active Carrier Self-Defense

   - Near-term missile and CIWS gun system improvements (low risk).
   - Mid-term ATBM extension of AEGIS (medium risk).
   - Near- to mid-term carrier active defense subsystems and systems:
     - A modified planar array, electronically scanned radar of the AEGIS type, not easily distinguishable from those on the other battle force combatants, as replacement for other carrier radars and with ATBM features (low risk);
     - A higher-frequency (e.g., X-band) active-array electronically scanned radar for horizon scan and close-in fire control and illumination for semiactive guidance (low risk);
     - Improved SPARROW-size ship self-defense missiles in the 400- to 600-lb class, fast enough for modest ATBM (medium risk);
     - Vertical launch bays for ship self-defense missiles (low risk);
     - Improved close-in guns (low risk);
     - Carrier-based active torpedo and rising mine defense, including means for detecting, locating, and intercepting the threat (medium risk); and
     - Cooperative engagement systems for the carrier and the battle force (medium risk).
   - Unconventional weapons:
     - Directed-energy and hypervelocity kinetic-energy weapons (long term; high risk); and
     - Low-yield nuclear warheads for air defense against violently maneuvering targets or those (such as nuclear) whose warheads must be destroyed (mid term; medium risk).

4. Propulsion and Other Electrical Systems (mid to long term)

   - Advanced, safe, high-power-density reactors (long term; high risk).
   - Long-life reactors (mid term; medium risk).
   - High-power-density, safe, power conversion and conditioning systems, applicable to electric drive; electric catapults and arresting gear; electrodynamic armor; ultrahigh-energy weapons,

including directed-energy and hypervelocity kinetic-energy weapons (medium risk).

- Electric drive, including motors, transmission systems, and retractable pod and counterrotating propeller designs (medium risk).
- All-electric "yellow gear" (aircraft and munitions-handling equipment), to ease operations on hangar decks enclosed to reduce ship radar signature, and to reduce fuel and maintenance requirements and IR signature: fuel cells or high-power-density batteries are the pacing items (medium risk).

5. Radio-Electronic and Acoustic Battle Management (REABM) (Technology and systems in this area are being developed continually as part of the total carrier system; some advanced elements are available now, and others will become available during near-, mid-, and long-term periods; carrier system design must allow for modular upgrades as advanced new systems become available; some of the most important areas for carrier aviation strike warfare and for carrier defense are listed here.)

- Complete integration of the active carrier self-defense system with battle group defense including AAW and ASW, through a modular, modern, radio-electronic and acoustic battle management system including identification friend, foe, or neutral (IFFN) and all target acquisition and weapons management (low to medium risk).
- Enhanced, multimedia, networked communication systems, including LPD/LPI features to the extent feasible and necessary, to support REABM system integration within a battle group and connectivity with the external world and command structure (medium risk).
- Low observable sensors and sensor systems, and also those pertinent to counter-LO (including the aircraft-related radars noted under (1), above (medium to high risk).
- Advanced targeting systems for strike warfare, compatible with aircraft advances noted under 1, above, including "forward pass" techniques and subsystems for both strike and defense, with appropriate data link capacity and multimode battle integrity (medium risk).
- Family of broadly defined, advanced EW systems (including ECM, electronic counter-countermeasures [ECCM], jammers,

decoying, deception, and so on) to work in conjunction with signature management and active defense of carrier for total carrier defense (medium risk).

- Improved battle group command center designs, to incorporate added capabilities provided by above advances and to enable modular upgrades as the technology advances. Centers need not be confined to carriers, but should be capable of integration into carrier design (low risk).

6. Advanced Logistics and Manpower Engineering (near to mid term; all low risk)

- All areas affecting personnel selection and assignment; habitability; imbedded simulation and training; computer-based operation, maintenance, and support systems for the ship, aircraft, and weapons, with special attention to reliability, maintainability, and efficient use of personnel; rapid aircraft turnaround concepts; all applications of automation to these purposes and to ship operation and damage control—all with the purpose of making the carrier system and its operations more effective and economical with fewer people.
- Improving the design of carrier and underway replenishment ships to operate together as a system, to achieve more rapid replenishment.
- Attention in ship design to capturing any volume saved by above measures to apply to passive protection and increased sustainability.

7. Special Opportunities—opportunities are available to make special gains in understanding carrier systems that, if capitalized on, can contribute invaluable data for mid- to long-term carrier design. Among the most interesting are the following:

- Use of the FORRESTAL, which is to be transferred to training status in 1992, as a test bed to experiment with several of the concepts described in this report, for defense, logistic support, crew reduction, and operations (medium risk).
- Design and model studies of all aspects of large semisubmersible ships, with special attention to the technical problems, signature reduction, enhanced survivability, better cost estimates, and

changed operational concepts in the long term (low risk for research; high risk for ship).

- Large-scale structural model experiments (possibly including a highly instrumented live fire test of a carrier destined to be sold for scrap), to help quantify better than is now possible the effects of underkeel torpedo explosions, to aid design studies of passive protection of carriers and other large ships (medium risk).